Energy to Power Solutions

Novel Cryogenic High Voltage Breaks (CHVB)

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Topic: 37c

Grant: DE-SC0021608

Energy to Power Solutions

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Outline

- e2P Overview
- Program Motivation
- Phase II Program Overview
- CHVB Schematic, Design, & Analysis
- CHVB Testing
- Commercial Outreach
- Path Forward

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e2P – A Company Introduction

Energy to Power Solutions (e2P)- performs **early-stage R&D** of both Low Temperature Superconducting (LTS) & High Temperature Superconducting (HTS) devices, their associated cryogenics, and cryogenic High Voltage (HV) components→ enabling technologies for **military, space, fusion energy, commercial &** ***medical application applications***

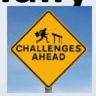
- **Founded 1999**
- ~50 % (US Govn't contracts) & ~50 % (commercial)
- Labs Located @ TCC in Tallahassee, FL

Program Motivation

- Cryogenic High Voltage Breaks (CHV-*Breaks*) & Bushing (CHV-*Bushings*) electrically isolate cryogenic devices & equipment operating at High Voltages (HV) from grounded components & structures. CHV-Bushings also transmit electrical power into cryogenic space.
- State-of-the-Art (SOA) *ceramic* CHVB's are ***notoriously unreliable*** and prone to frequent *micro-cracking* & hence *leaking*.
- CHVB's leaking into cryogenic vacuum spaces can be prohibitively expensive to repair (e.g. ITER, CERN, etc.) or lead to premature failure (e.g. power equipment)
- For V_{op} > 100 kV or non-magnetic there is no suitable commercial product
- **Requirements:** Low cost, mechanically robust, HV standoff, radiation resistant, hermetic, repeated thermal cycling, high internal pressure, non-magnetic

Phase II Program Overview

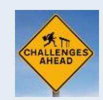
Work Scope A: Thermally Insulating CHVB for ANL w/ R. Vondasek

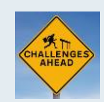
- V_{op} >150 kV 

- Interior medium: flowing LN2, Exterior medium: atmosphere 

- Radiation: No
- Mechanical/Structural: NA
- Quantity: 2-3
- Commercial opportunity: Low

Work Scope B: Radiation Tolerant CHVB for Commercial Fusion

- V_{op} ~ 30 kV
- Interior medium: GHe, Exterior medium: vacuum 

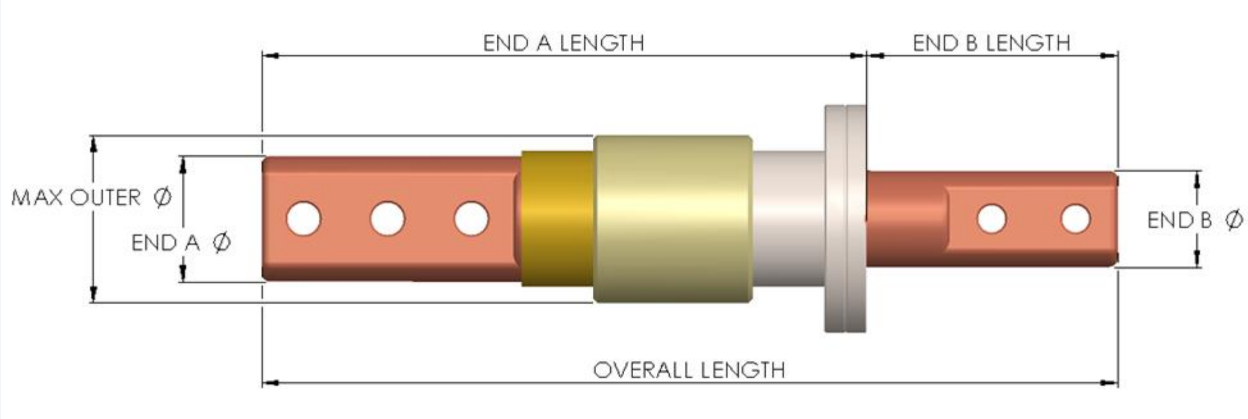
- Radiation: 10 MGy
- Mechanical/Structural: 500 PSI internal pressure 

- Quantity: > 1000
- Commercial Opportunity: Very high

Phase II Program Overview

Work Scope C: General R&D for CHV-***Bushing*** Design & Fabrication

- V_{op_DC} ~ 1→5 kV & V_{rms_phase} 1→ 15 kV_{rms}
- I_{op_DC} ~ 1→10 kA & I_{rms_phase} 1 → 5 kA_{rms}
- Interior medium: vacuum or cryogenic liquid
- Radiation: NA
- Mechanical/Structural: 100 PSI internal pressure
- Thermal cycles: > 100
- Quantity: > 20
- Commercial Opportunity: medium

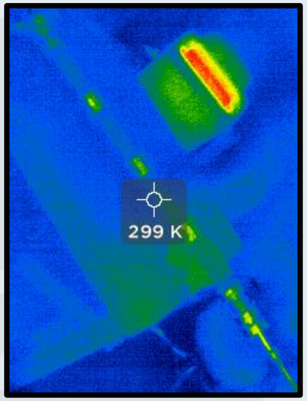


CHVB Requirements

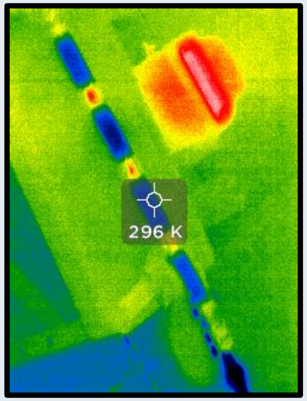
Properties		E2P CHVB	SOA Ceramic	PI Testing	PII Testing
Electrical	High Voltage >100kV				X
	Breakdown			X	
	Creep			X	
Mechanical	Thermal Cycling Resilience			X	X
	Compressive Strength			X	
	Tensile Strength				X
	Torsional Strength				X
	High Internal Pressure				X
Other	Hermetic			X	
	Accelerated Life*				X
	Non-magnetic			X	
	Radiation Resistance				X
*4 commercial orders	Low Cost				X

Testing: Thermal Gradient

- LN_2 pumped through array over 15-minute period
- Thermal imaging used to capture thermal gradient and determine cold points
- Surfaces remained ≥ 295K (reference device in background @ ~318K ~45C)
- Device should not develop exterior surface condensation under expected conditions
- 2nd Gen unit needed for Grid applications



T_1 = 299K
t_1 = 0m



T_5 = 296K
t_5 = 7m

T_8 = 295K
t_8 = 15m
T_{ref} = ~318K

Radiation Tolerant Epoxy Evaluation

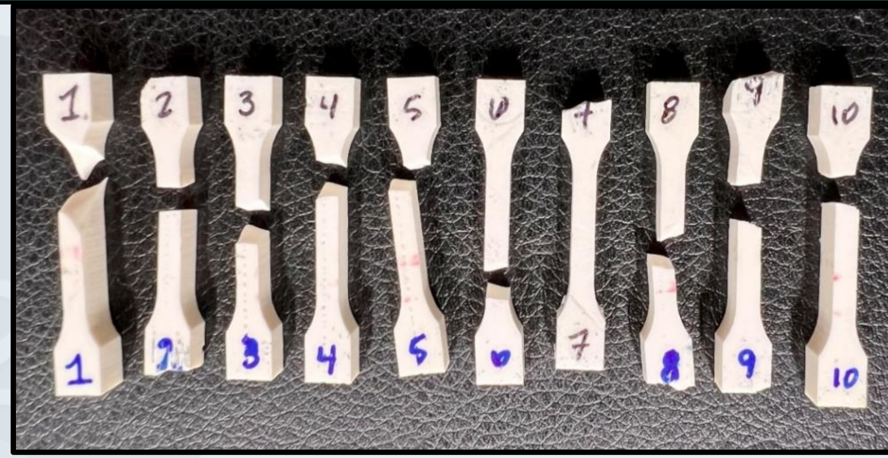
- Mechanical testing of:
  - Tensional Strength (ASTM D638)
  - Compressive Strength (ASTM E9)
  - Torsional Strength (ASTM D4065)
- ASTM compliant procedures include:
  - sample design
  - Fabrication
  - Testing
  - post-processing of data
- Procedures will be used to determine compliance of materials and components

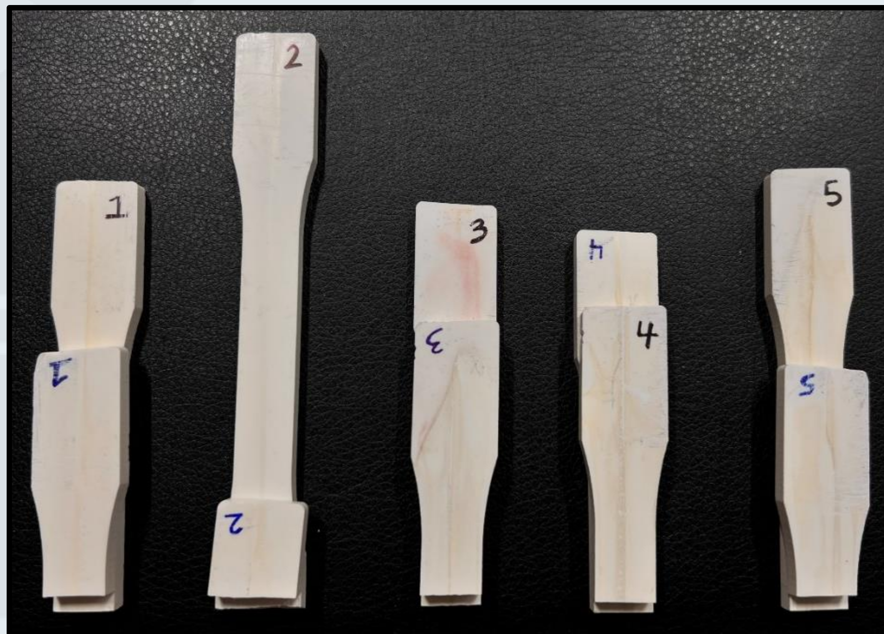
Radiation Tolerant Epoxy Evaluation

Mechanical Testing:

- Pictured top: Small form factor (SFF)[1] tension samples
- Pictured bottom: Large form factor (LFF) tension samples
- Both small and large samples utilize the same ASTM D638 & E9 “dog-bone” shape and proportions i.e. gauge[2] length is ~4x the gauge width

  1) shape, proportions
  2) reduced cross-sectional area section of sample





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Testing: Mechanical Data

Argonne NATIONAL LABORATORY

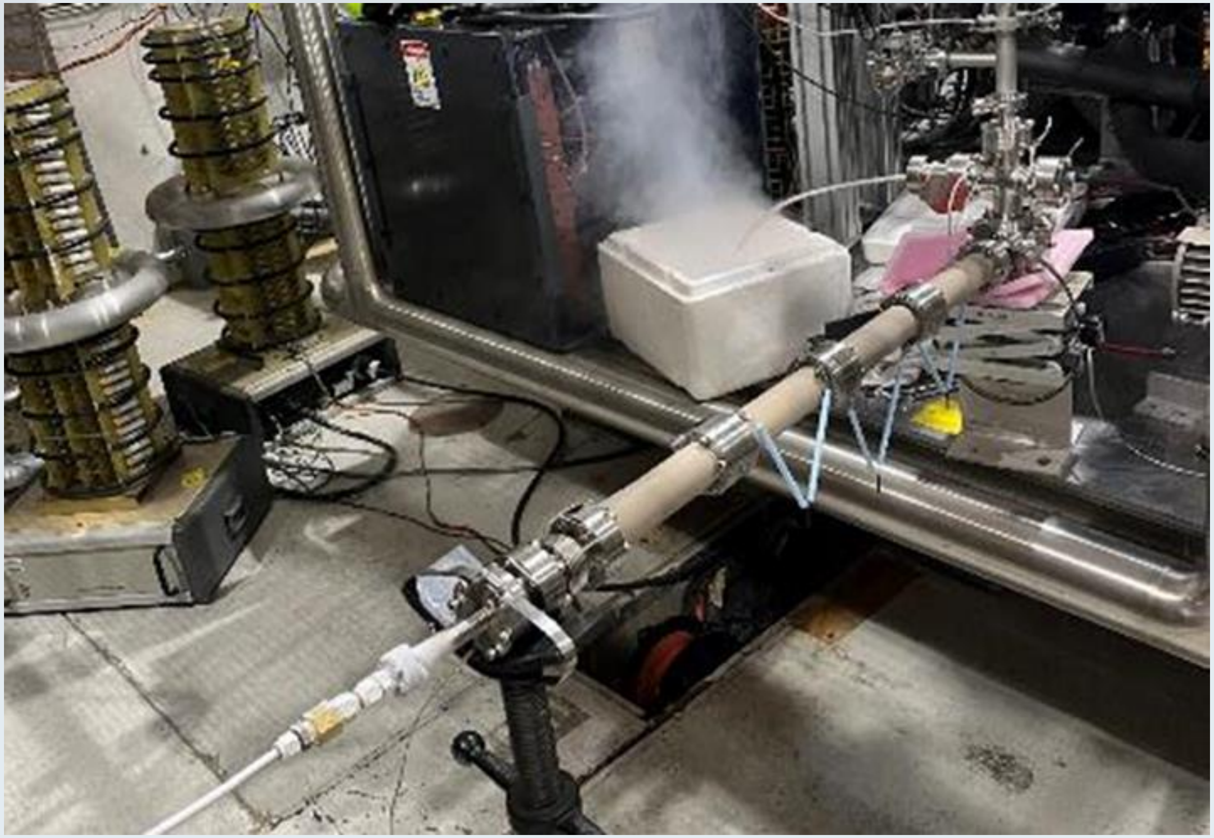
- UTS data for epoxy PEB-C
- Results inconsistent: emphasizing need for process improvement

Sample	Ultimate Tensile Strength (MPa)	
	Small FF	**Large FF**
1	-	14.96
2	29.52	-
3	-	25.65
4	-	22.10
5	27.66	13.36
6	25.32	-
7	-	-
8	24.05	-
9	26.12	-
10	28.24	-
Average ± Standard Deviation	**26.82 ± 2.02 MPa**	**19.02 ± 5.82 MPa**

CHVB Testing @ ANL

Test Conditions: flowing LN2 up to 2 L/min

Time (hh:mm)	Voltage (kV)	Current (mA)
13:40	50	0.26
13:45	75	0.44
13:48	90	0.54
13:50	100	0.60
13:55	100	0.60
13:56	110	0.69
14:00	110	0.69
14:35	120	0.76
14:40	130	0.86
14:47	140	0.95
14:56	150	1.05
15:01	150	1.05



Summary

- **Work scope A: >100 % complete**
  - Field test @ ANL (R. Vondrasek) → 100 %
  - ΔT_{OD} < 10 K w/ LN2 @ 2 liters/min on interior up to 150 kV
- **Work scope B: Low Cost, High Throughput Manufacturing 100 % Complete !!**
  - Develop low-cost volume manufacturing techniques
  - Develop low-cost/repeatable/reliable high volume LN2 thermal cycle testing techniques
  - Develop low-cost/repeatable/reliable high volume GHe testing techniques
- **Work scope C: Component Test Multiple Prototypes**
  - Continue characterization
    - UTS
    - UCS
    - Torsional
    - Internal pressure to > 2000 PSI
    - Larger diameters up to 16 “
  - Expand into CHV-Bushings
    - DC – Magnet Applications
    - AC – Power Applications

Acknowledgements

- Funded by DOE under SBIR contract DE-SC0021608
- DOE PM Michelle Shinn, Ph.D.
- ANL Rick Vondrasek
- e2P Trever Carnes, Ben Andrews, Luke Remillard

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