Risk Reduction Testing of Superconducting Coils for the High Efficiency Megawatt Motor

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Motivation

- Enable **reduced energy consumption, emissions, and noise of commercial transport aircraft** via electrified aircraft propulsion
- NASA's High-Efficiency Megawatt Motor (HEMM) sized as generator for NASA's STARC-ABL concept

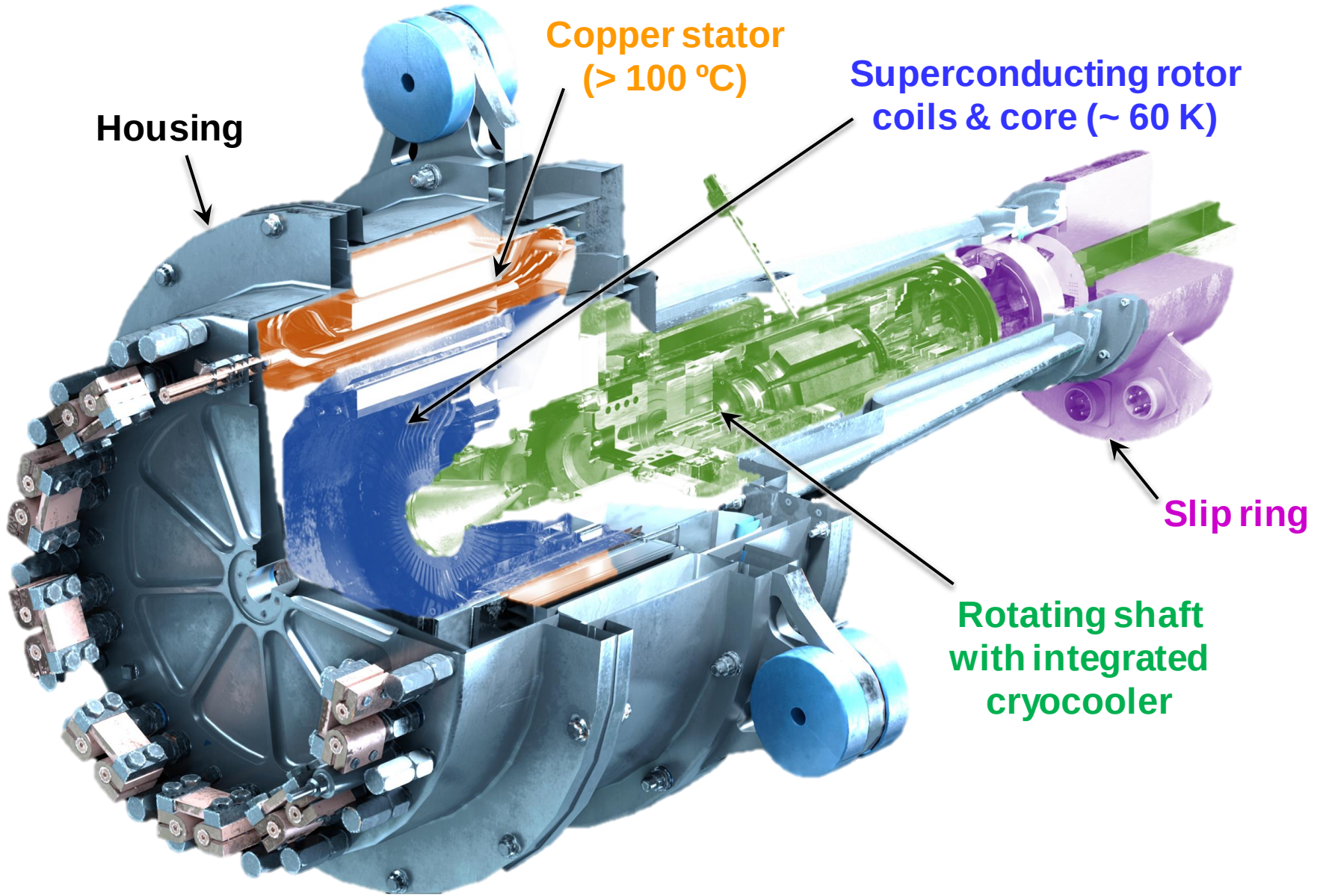
Performance impact of HEMM

	Fuel burn with HEMM + advanced power electronics	Baseline
Refined assessment [1] (higher fidelity power system & thermal management)	–2.5% to –2.8%	Refined STARC-ABL rev. B2.0

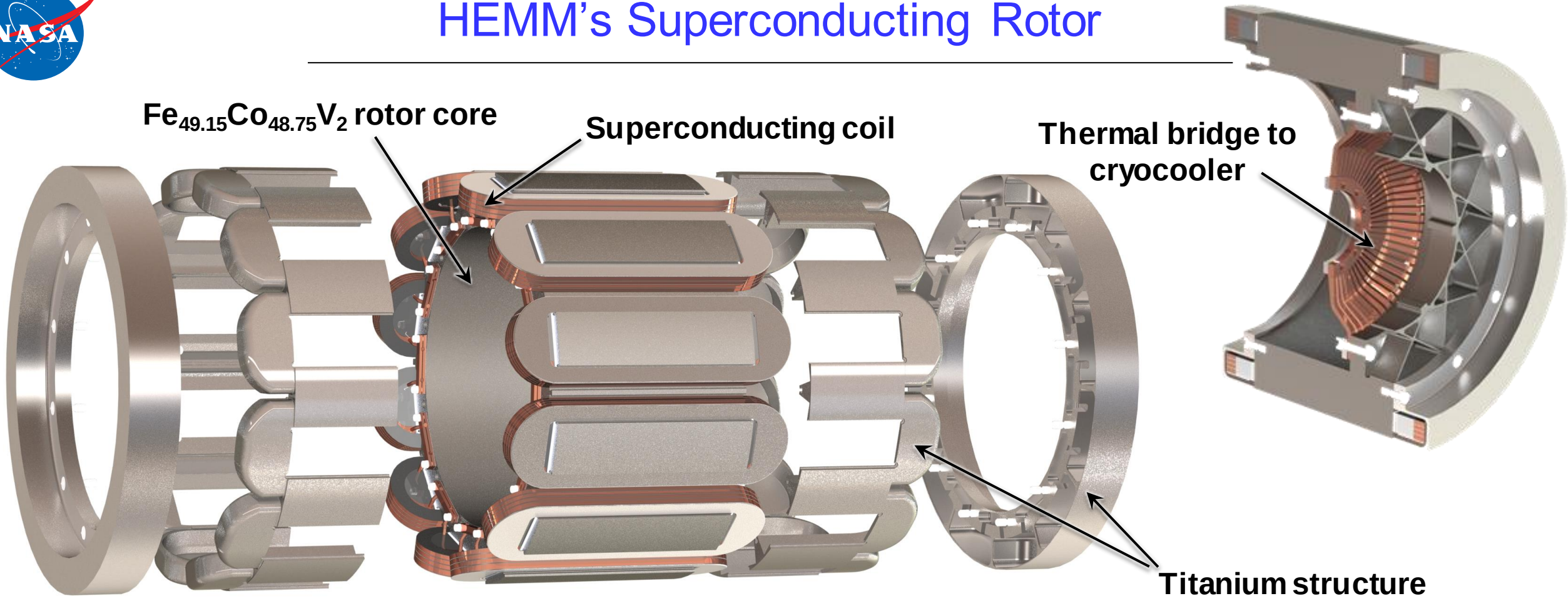
1. Schnulo, S.L. et al., Proc. of EATS, 2020.

NASA's High-Efficiency Megawatt Motor (HEMM)

Parameter	Value
Rated continuous power	1.42 MW
Nominal speed	6,800 rpm
Tip speed	107 m/s
Rated torque	2 kNm
Electromagnetic specific power goal	16 kW/kg
Efficiency goal	> 98%



HEMM's Superconducting Rotor



Parameter	Value
# poles (coils)	12
Superconductor	2G HTS

Parameter	Value
Coil configuration	No-insulation quadruple pancake
# turns per coil	600 (150 per layer)
Coil mass	~0.6 kg

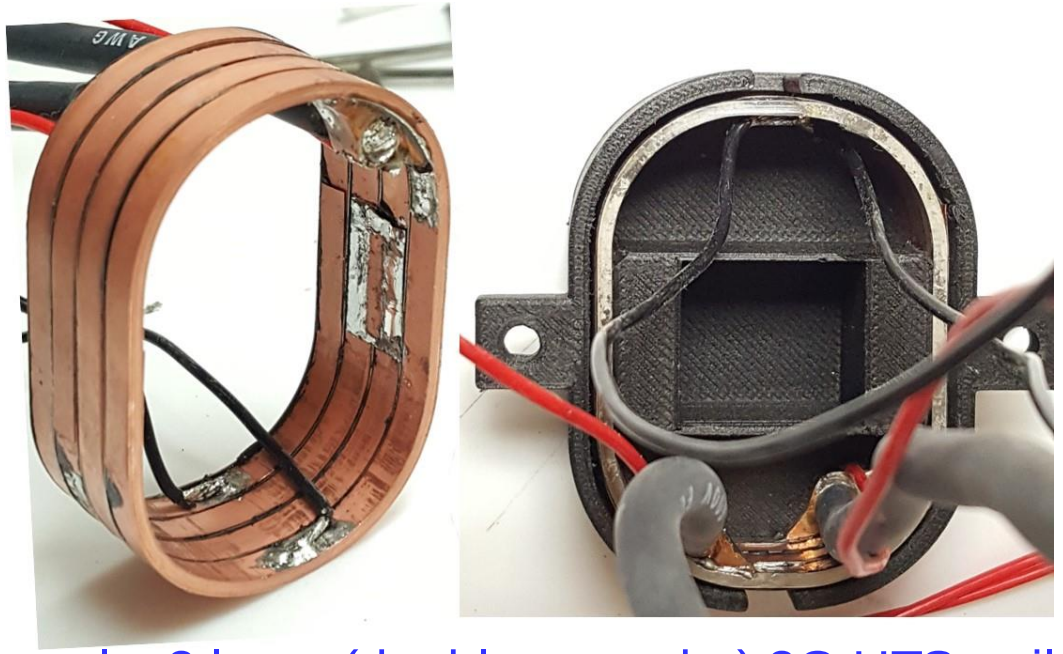
Thermal Cycling of Stationary Superconducting Coils

Motivation: thermal stresses in the superconductor arising from CTE mismatches cause failure or critical current degradation of most 2nd generation high temperature superconducting (2G HTS) coils

Objectives:

- Fabricate representative HEMM coils composed of 2G HTS
- Demonstrate that coils survive repeated thermal cycling between 293 K and 77 K with minimal or no degradation

Sub-scale, 4 layer (quadruple pancake) 2G HTS coil



Full-scale, 2 layer (double pancake) 2G HTS coil

Thermal Cycling – Procedure & Performance Metrics

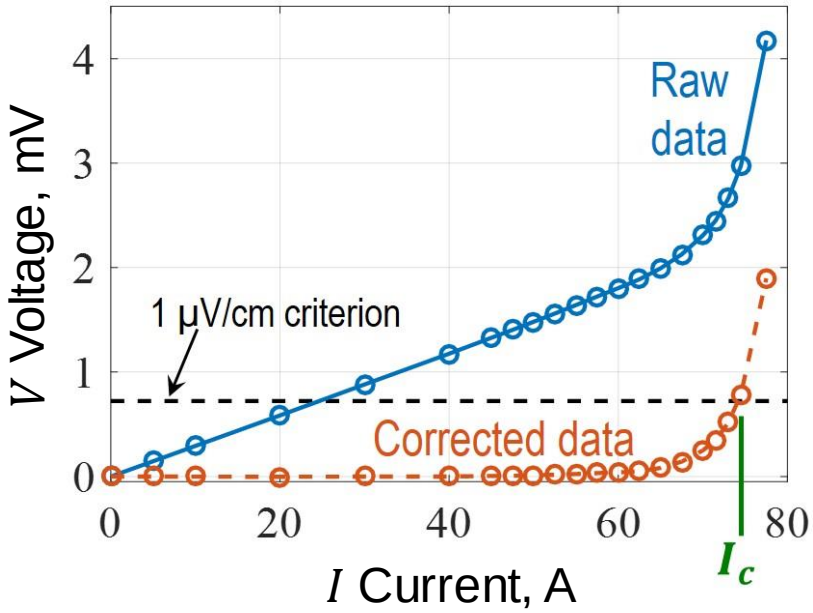
Summarized test procedure

1. Very slowly lower the coil into the LN2 bath
2. Measure electrical response of the coil
3. Calculate performance metrics
4. Thermally cycle coil
   a. Remove coil from LN2 bath, air quench for 5 minutes
   b. Warm coil with fan for ~4-5 minutes
   c. Very slowly lower coil into LN2 bath
   d. Wait 5 minutes
5. Repeat steps 2-4 until test completed

Performance metrics used to assess degradation

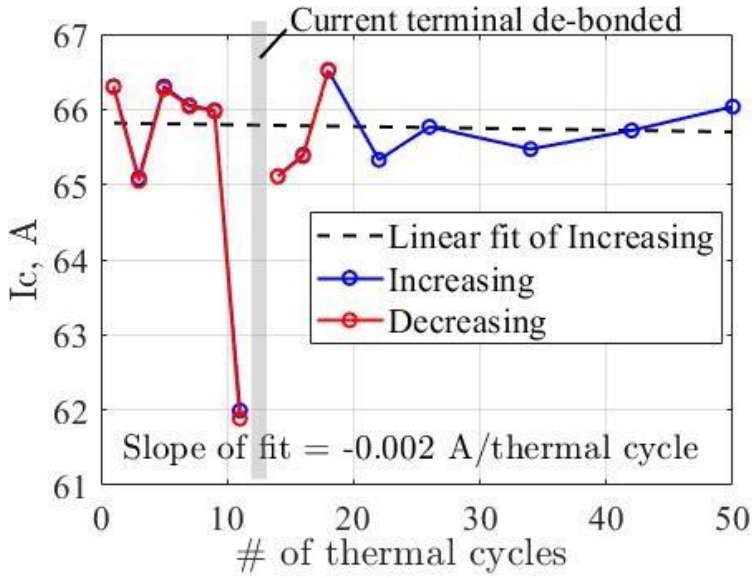
$$V = V_c \left(\frac{I}{\boldsymbol{I_c}} \right)^{\boldsymbol{n}}$$

where $V_c = 1 \frac{\mu V}{cm} \cdot \text{conductor length}$

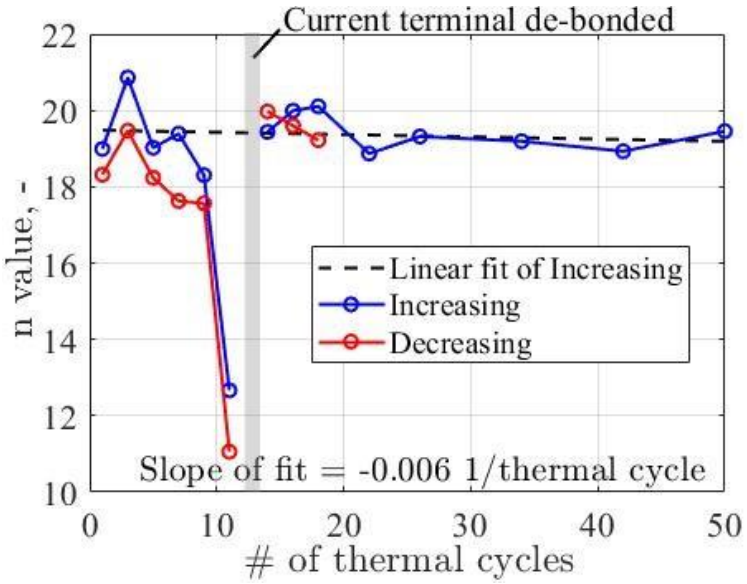


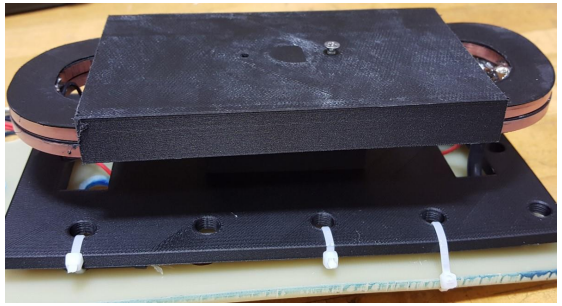
Thermal Cycling – Results

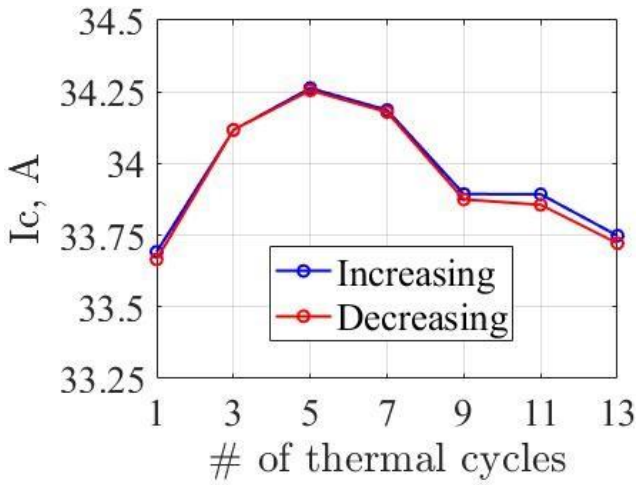
Critical current

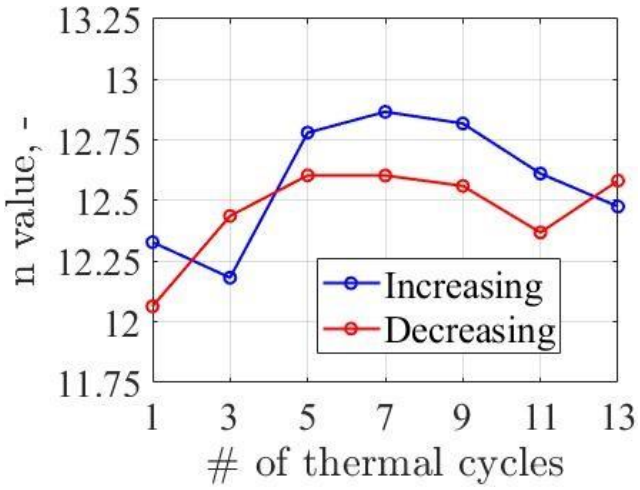


n-value







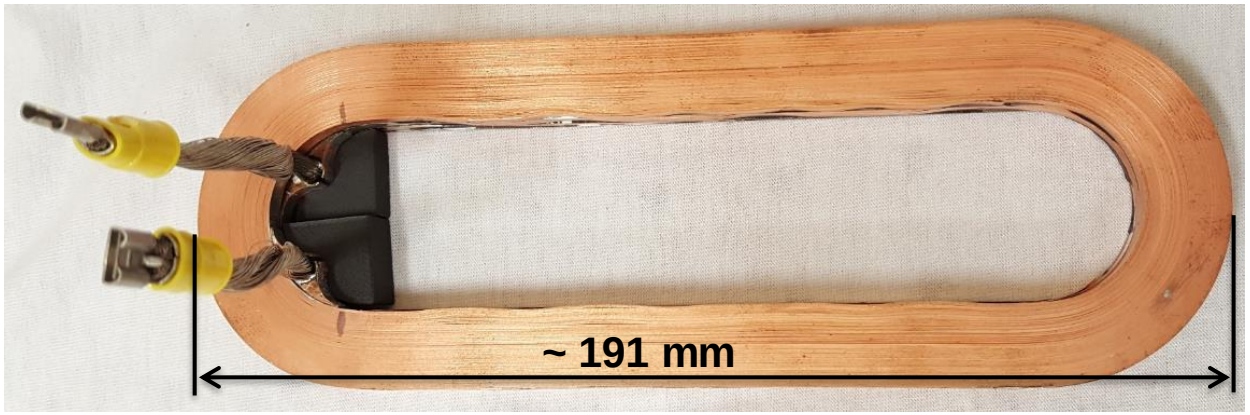


Superconducting Coils Under High Speed Rotation

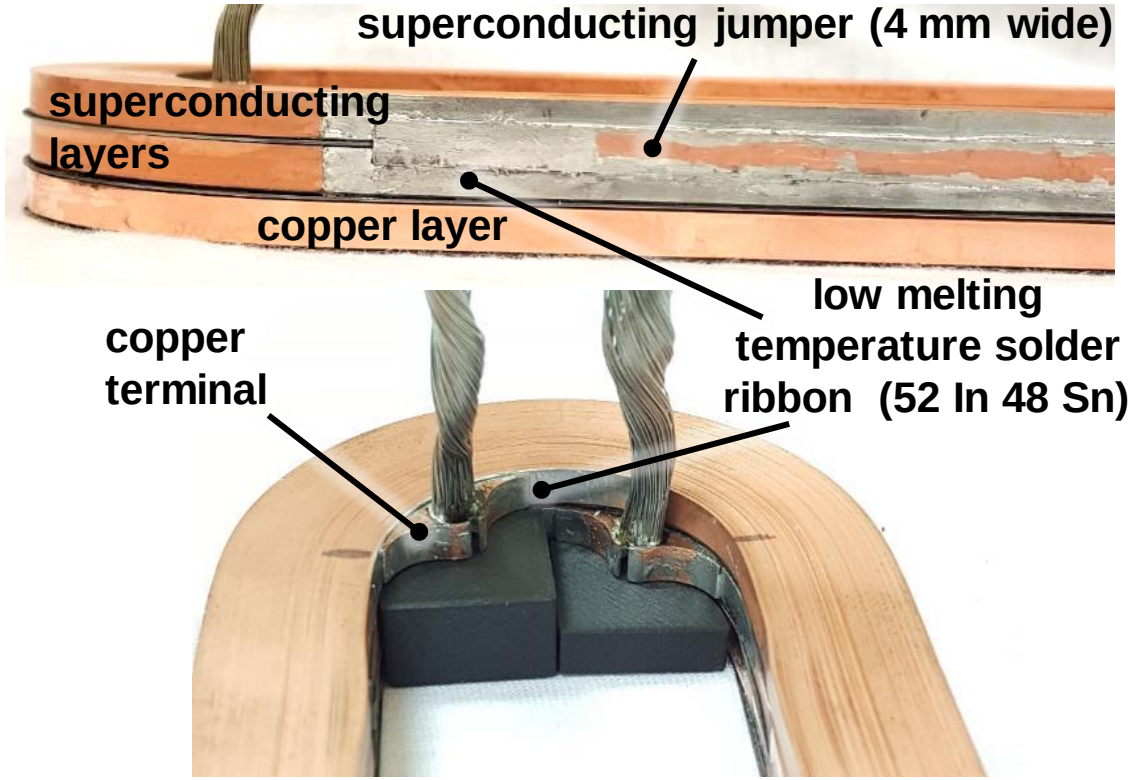
Motivation: In rotating machines, centrifugal stresses are often large · accurate modeling is very computationally expensive · little material property data available

Objectives:

- Fabricate representative HEMM coil
- Demonstrate that the HEMM coil can maintain performance under the mechanical loading environment of the HEMM rotor design
  or
  Quantify the limiting speed and stresses that the coil can sustain without appreciable degradation

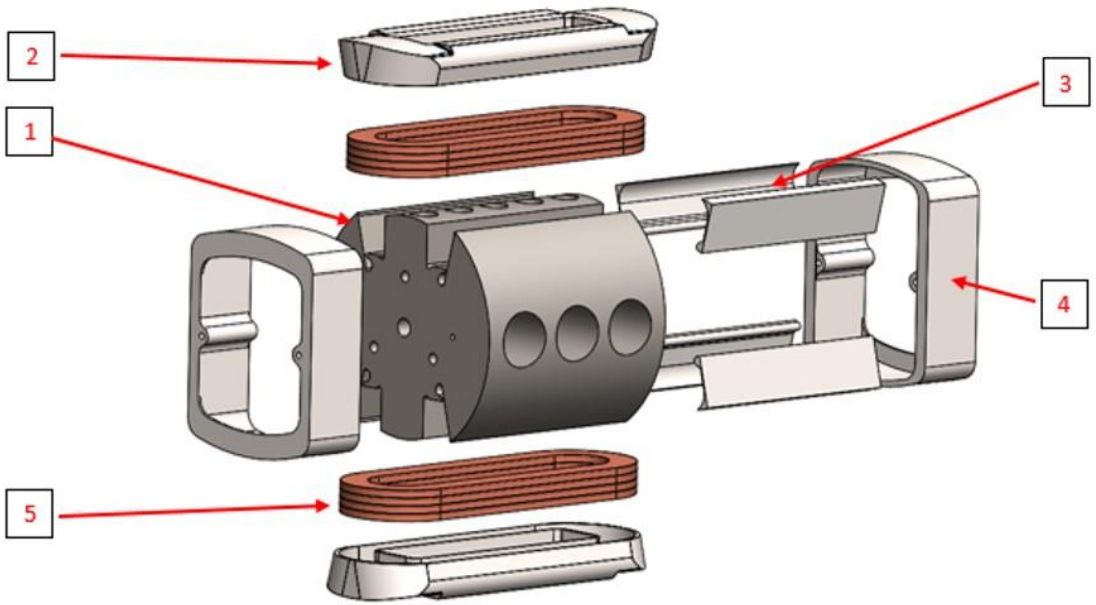


Test coil: full-scale, 3 layer (triple pancake) with two 2G HTS layers & 1 Cu layer



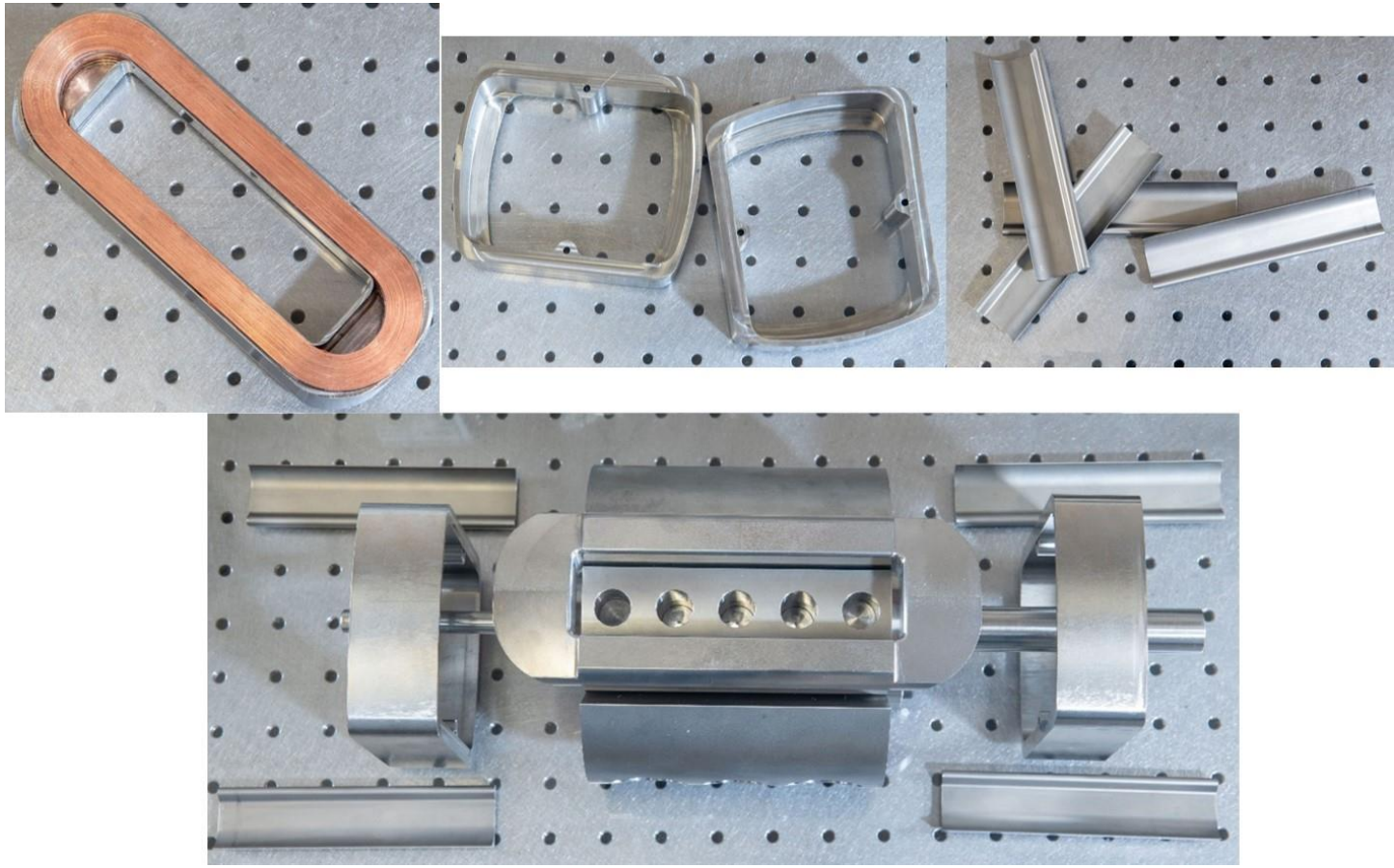
High Speed Rotation – Test Article

Exploded view of test article



1. Solid 4340 steel rotor
2. Two Ti-6Al-4V coil fixture cups
3. Four Ti-6Al-4V dovetail fixture restraints
4. Two Ti-6Al-4V end winding retaining hoops
5. Two coils: 1 test coil, 1 dummy copper coil

Images of test article

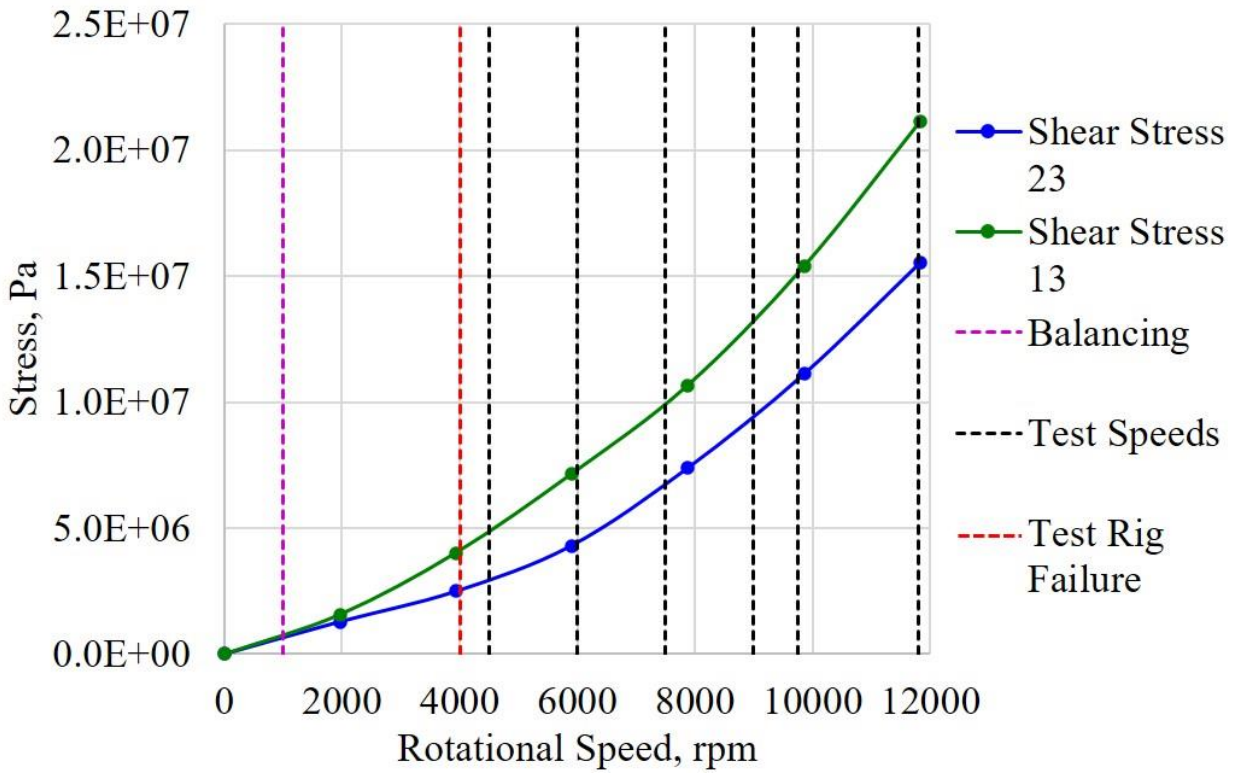


High Speed Rotation – Test Procedure & Test Matrix

Summarized test procedure

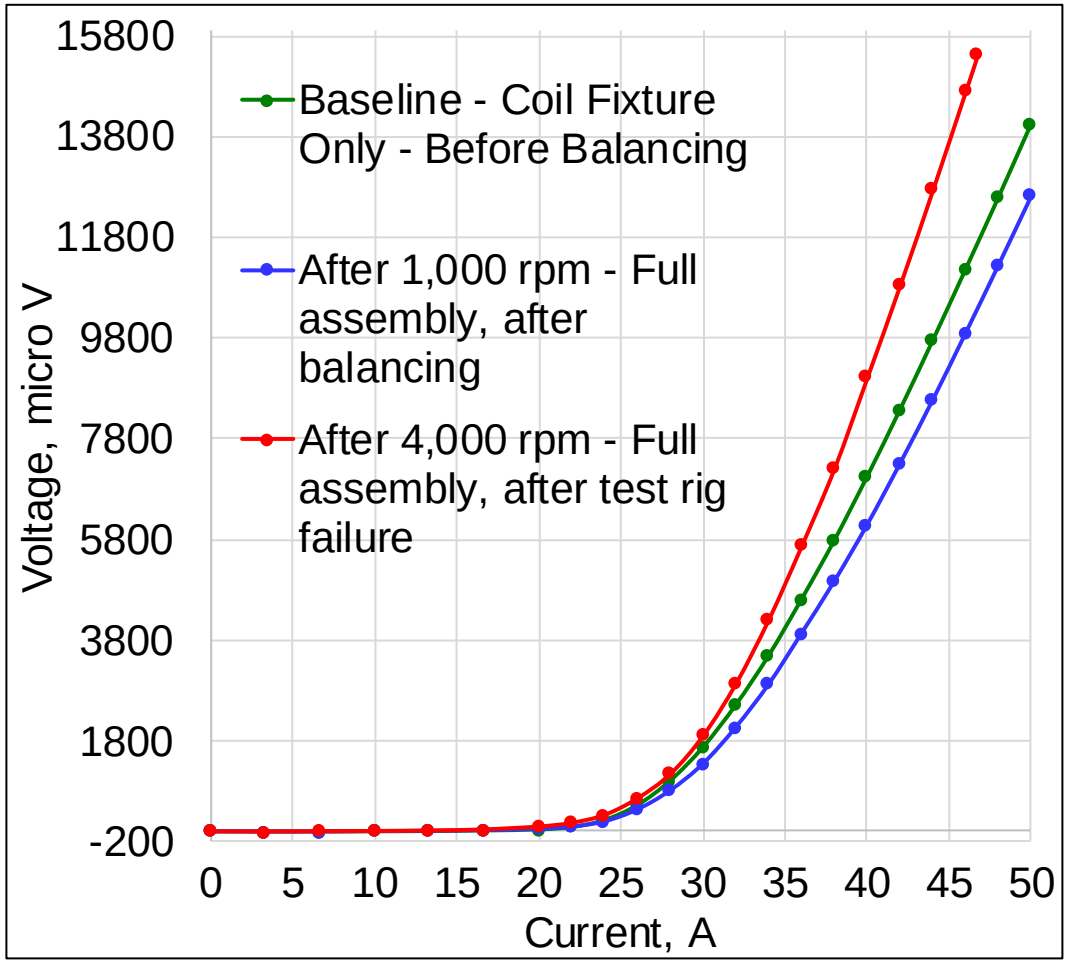
1. Measure baseline electrical response of the coil in LN2
2. At room temperature, slowly accelerate test article to speed, hold for 10 s to 1 min, slowly decelerate
3. Measure electrical response of the coil in LN2
4. Calculate performance metrics
5. Test article warmed up overnight
6. Repeat steps 2-5 until test completed

Critical shear stresses in the 2G HTS coil versus rotation speed of test article

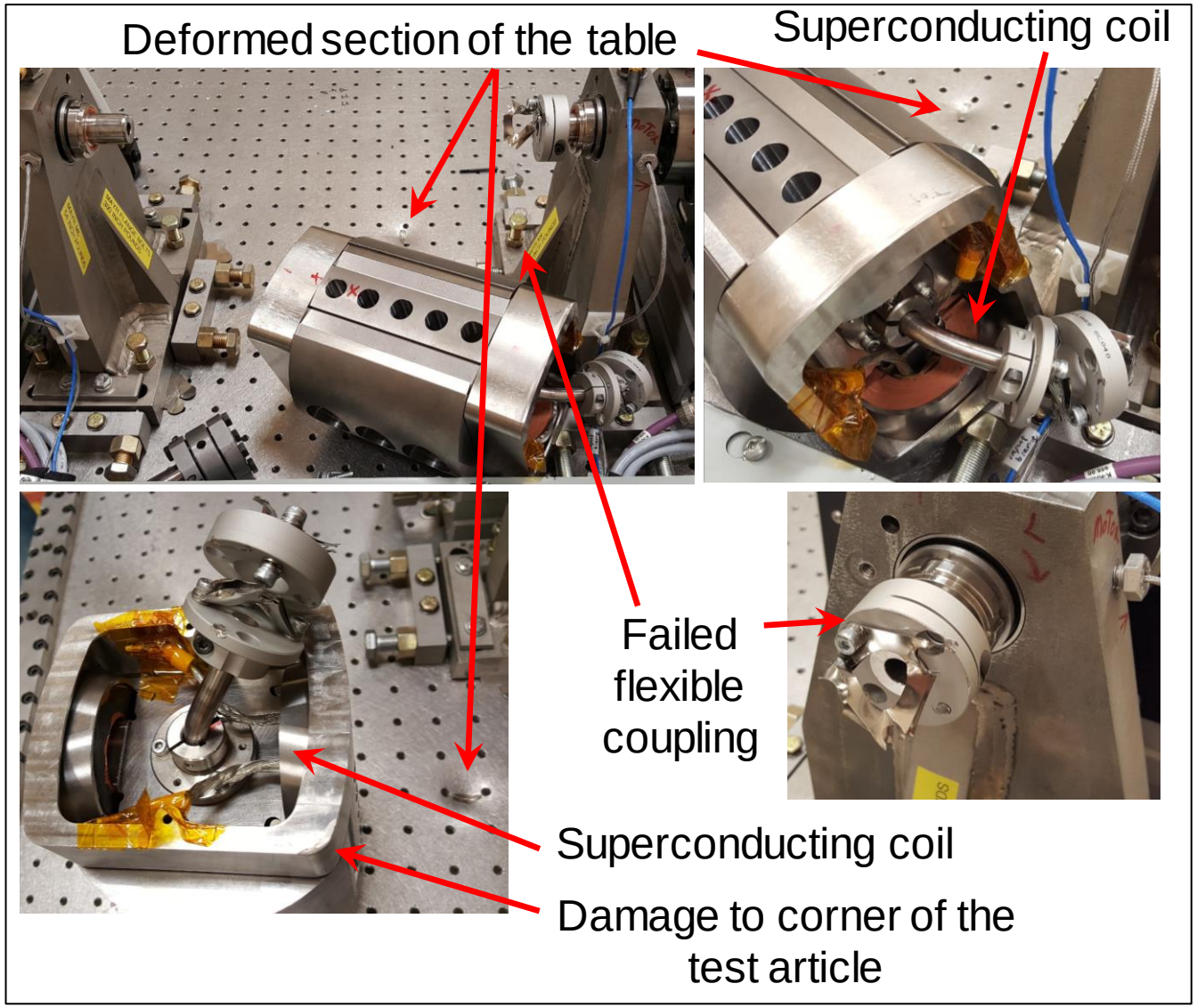


High Speed Rotation - Results

Early results

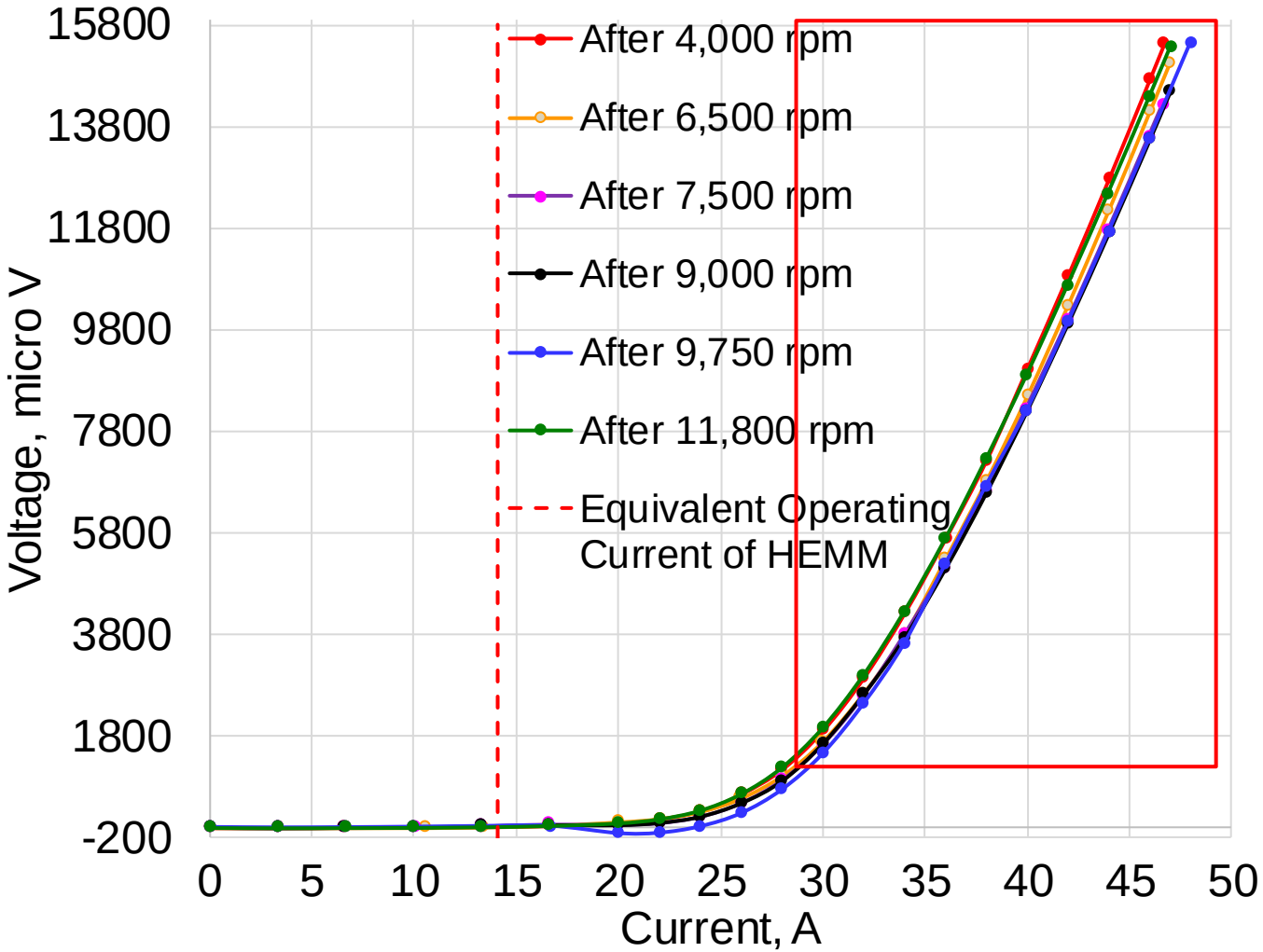


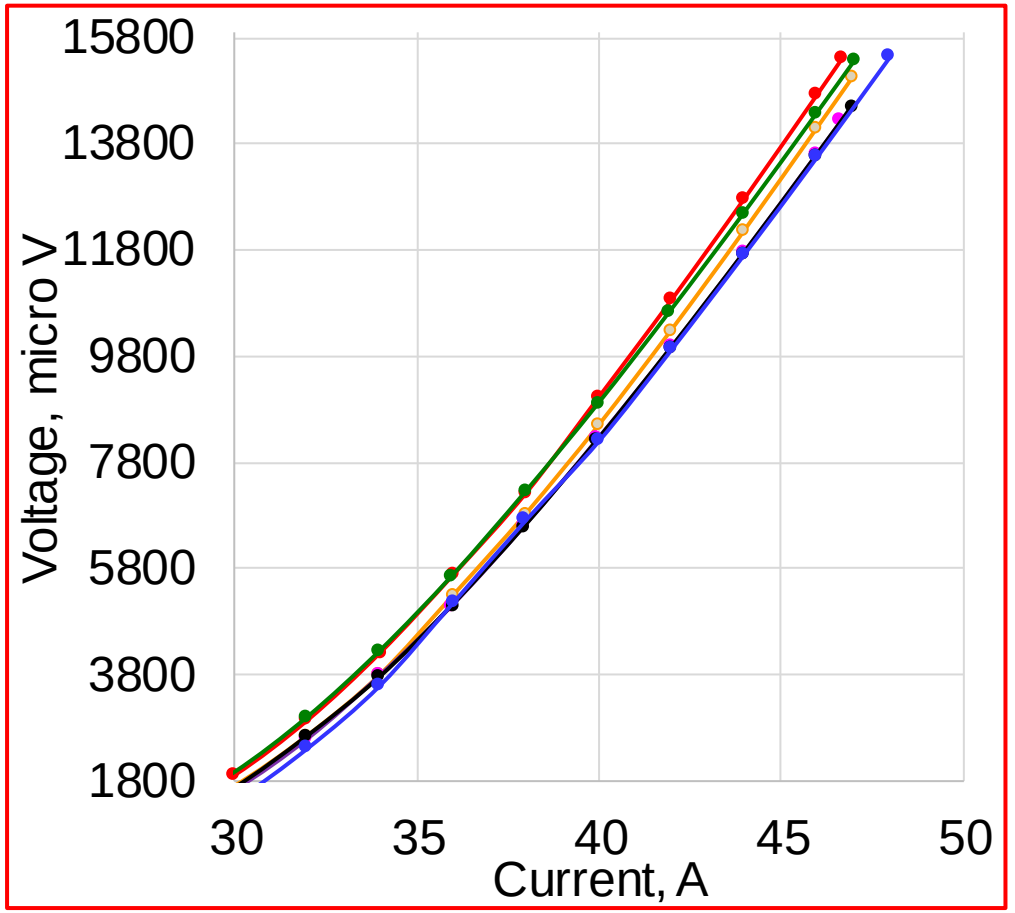
Test article after rig failure



High Speed Rotation - Results

Results after establishing new baseline (4,000 rpm curve)





Conclusions

Thermal cycling

- Two 2G HTS coils thermally cycled between 77 K and 293 K up to 50 times
- Sub-scale coil experienced temporary degradation due to current lead detachment
- Variation in performance metrics was small (< 1.5 A in the critical current; < 3.5 in the n-value)

High speed rotation

- One 2G HTS coil rotated up to full centrifugal load
  - Stress components in coil reached 1 to 7.4 times design value
- Only degradation of the coil resulted from a test rig failure

Future work

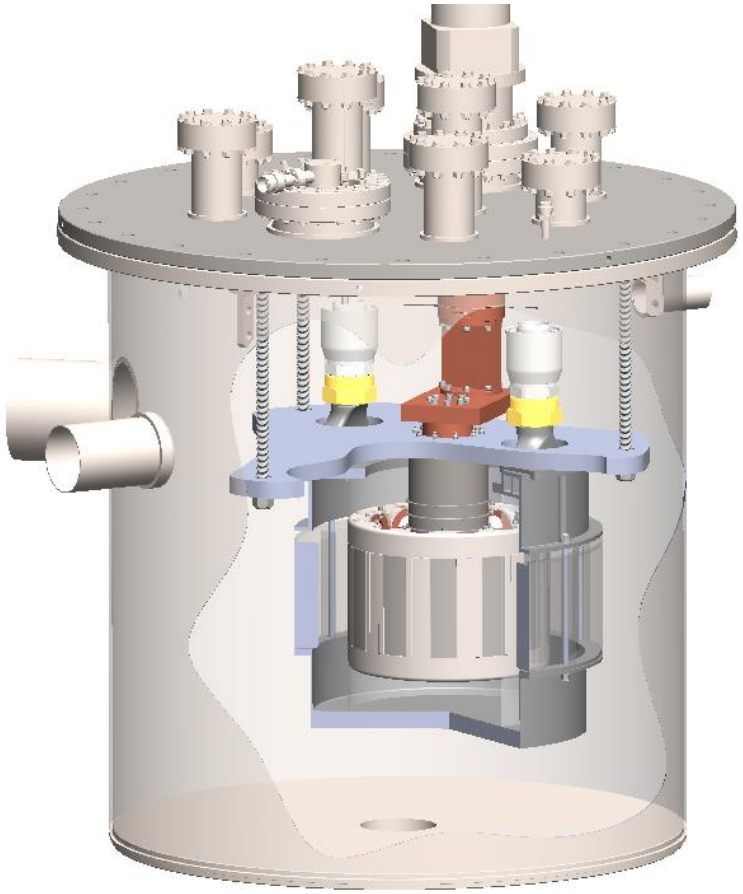
Testing

- Test full-scale HEMM rotor at nominal operating conditions (at ~60 K & full DC current) in ICE-Box test rig at NASA GRC
  - Demonstrate ability to conductively cool the rotor coils
  - Demonstrate ability to stably operate superconducting coils

Analysis

- Finalize electromagnetic, structural, & thermal design for upcoming critical design review

NASA GRC's ICE-Box test rig & CAD of its use for testing HEMM's rotor



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THANK YOU


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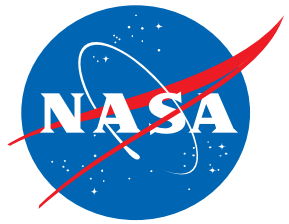
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