200 kW cryogenic propulsion unit development progress

Min Zhang (min.zhang@strath.ac.uk)
Applied Superconductivity Laboratory
Department of Electronic and Electrical Engineering
University of Strathclyde
Applied Superconductivity Laboratory

- Launched in 2019
- Two research labs around 200 m²
- Two Professors, Three RAs and ten PhD students

1. Cryogenic propulsion
2. HTS fusion
3. HTS for power applications
How to develop an ideal HTS machine with high performance?

>= 15 kW/kg, >= 96%

**AC-capable HTS stator winding**
- Multi-filament HTS cable

**Brushless HTS rotor**
- Large trapped field HTS magnet
- Persistent operation of HTS coils

* GE drawing
AC-capable stator winding development

1. Insulation material selection
   1. Ic degradation test
   2. Breakdown voltage test
   3. Power/thermal cycling

2. HTS material selection
   1. Thermal cycling
   2. Ic test
   3. Tc test

3. AC-capable winding selection
   1. Ic test
   2. Transport AC loss test
   3. Total AC loss test
AC-capable armature winding development

- Insulation material selection:
  Power cycling, thermal cycling, optical microscopy inspection, Ic test
AC-capable armature winding development

- HTS material selection: thermal cycling -> Ic test

![I-V curve after 20 thermal cycling](image1)

![I-V curve after 100 thermal cycling](image2)

![I-V curve after 20 thermal cycling](image3)

![I-V curve after 100 thermal cycling](image4)

Supplier 1

Supplier 2
AC-capable armature winding development

- Multi-filament HTS cable to minimize AC losses [1]
  1. soldering-stacking 1mm HTS cable [2]
  2. Insulated-stacking 2mm and 1mm HTS cables
  3. Striated 4mm cable

[1] Manuscript in collaboration with Airbus ASCEND under review for IEEE TAS
AC-capable armature winding development

- Transport AC loss via electrical method

Results (comparing to a 4mm standard coil: coil 1):
1. Striation (1mm) reduces transport loss by 42%
2. Soldering-stacked (1mm) reduces transport loss by 80%
3. Insulated-stacked (2mm) reduces transport loss by 78%
4. Insulated-stacked (1mm) reduces transport loss by more than 90%
AC-capable armature winding development

• Total AC loss via calorimetric method at 77 K

Results (comparing to a 4mm standard coil: coil 1):
1. Striation (1mm) reduces total AC loss by 28%.
2. Soldered- stacking (1mm) reduces total AC loss by 26%.
3. 2mm*2 multi-filament coil (coil 5) reduces total AC loss by 68%.
4. 1mm*4 multi-filament coil is expected to perform better but damaged during testing
AC-capable armature winding development

• Total AC loss via calorimetric method at 20-77 K (on-going)
Brushless HTS rotor

- Large HTS bulks subject to damage easily
- Large HTS ring has a low HTS filling ratio
- A new hybrid HTS trapped field magnet *

* Manuscript under review for SUST

Brushless HTS rotor

• A new hybrid HTS trapped field magnet *

Fig. 4 Field distribution at 2 mm above the surface of the HTS hybrid magnet

2 T peak at motor armature mean diameter

* Manuscript under review for SUST
Brushless HTS rotor

Brushless control for persistent currents in joint-less HTS coils at 77 K

- No thermal leakage from current leads
- Minimized charging losses (only in ramping up and rotor field modulation)

20 K setup (on-going)
UK ATI Zero Emission Sustainable Transportation 2022-2024:

Objective for WP2.2:
To develop a cryogenic propulsion motor and its drive system
• Power density and efficiency step change for cryogenic/superconducting technologies >=15kW/kg
• Demonstrate voltage reduction below 800 V dc

<table>
<thead>
<tr>
<th>Definition</th>
<th>Value</th>
<th>unit</th>
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<tbody>
<tr>
<td>Magnetic loading peak</td>
<td>2-3</td>
<td>Tesla</td>
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<tr>
<td>Electrical loading</td>
<td>100</td>
<td>kA/m</td>
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<tr>
<td>Rated speed</td>
<td>1500</td>
<td>rpm</td>
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<tr>
<td>Rated voltage stator</td>
<td>300</td>
<td>V</td>
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<td>Temperature rotor</td>
<td>30-40</td>
<td>K</td>
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<tr>
<td>Temperature stator</td>
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<td>K</td>
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<tr>
<td>Power density</td>
<td>&gt;=15</td>
<td>KW/kg</td>
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</table>
Previous 10 kW partially axial-flux superconducting motor: between 2017-2022:

Steady tests for AC loss calculation

Transient tests with a cryogenic rectifier
New 200 kW cryogenic powertrain features:
1. Axial-flux fully HTS motor
2. Brushless operation
3. Two 100 kW cryogenic invertors
4. Neon thermosiphon rotational cooling
5. Helium gas circulation cooling