Design and manufacturing of AMaSED-2: A no-insulation HTS demonstrator coil for the space spectrometer ARCOS

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The HTS Demonstrator Magnet for Space (HDMS) project goals

1) Conceptual design of a HTS magnet for the magnetic spectrometer in space ARCOS

2) Design and manufacture a demonstrator coil AMaSED-2 for the ARCOS magnet
Astroparticle Research Compact Orbital Spectrometer (ARCOS)

- A toroidal high-field magnet
- A tracker, composed of silicon pixel detectors, which measures the charged particle trajectories in the magnetic field
- Plastic scintillators, which provide the trigger to select the desired event topologies.
Rigidity and bending strength

Rigidity:

\[ R = c \frac{p}{q} \quad [\text{V}] \]

Bending strength:

\[ \overline{B}_\varphi L(\varphi) = \int_0^L B_\varphi(r, \varphi) dr \]

Average bending strength:

\[ \langle \overline{B}_\varphi L \rangle = \frac{N}{\pi} \int_0^{\pi/N} \overline{B}_\varphi(\varphi)Ld\varphi \]
Requirements for the ARCOS magnet

- Average bending strength: 3 T m
- Inner toroid diameter: 500 mm
- Outer toroid diameter: 2000 mm
- Straight coil segment height: 1000 m
- Operating temperature 20 K
- Conduction cooled by a cryostat
- Lightweight structure
- Sufficient space available for detectors
Conductor requirements for the ARCOS magnet

HTS ReBCO tape:

- 12 mm wide, 100 µm thick
- \( J_e = 1200 \text{ A/mm}^2 \) at 4.2 K and 20 T
- Angle dependence: worst case conditions
- Field dependence: Fitting function
ARCOS magnet design

• 12 racetrack coil packs
• 2 winding layers per coil pack
• Engineering operating current density: 855 A/mm²
• Peak field: 11.9 T
• Total HTS tape length: 62 km
• Stored magnetic energy: 39.6 MJ
**ARCOS coil mechanical structure**

**Materials**
- Aluminium 2050-T84
- Copper bands
- Coil layer (insulation hidden)
- Magnet former
- Hole in magnet former
- Coil layer
- Cover plate
- Indentations

Note: Upper cover plate and insulation of upper winding layer are hidden in the figure.
ARCOS force analysis

<table>
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<tr>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
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<tr>
<td>$F_{in}$</td>
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<td>MN</td>
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<tr>
<td>$F_{out}$</td>
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<tr>
<td>$F_c$</td>
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</table>
ARCOS mechanical analysis

Static structural
Equivalent (von Mises) Stress

Note: Due to symmetry only one quarter of a coil pack is shown. The cover plate and insulation are hidden in the figure.
ARCOS intercooil structure

- Coil pack structure
- Inner intercooil structure
- Upper and lower intercooil structure
- Outer intercooil structure

Distance in millimeters:
- 0
- 250
- 500
- 750
- 1000 (mm)
Design and manufacture of AMaSED-2

AMaSED: Advanced Magnetic Spectrometer Experimental Demonstrator

Main goals for the demonstrator:

- Copper bands as current leads and layer jumps
- Test medium sized no-insulation coil
- Test design of aluminum structure
AMaSED-2 conductor requirements

HTS ReBCO tape:

- 12 mm wide, 100 μm thick
- $J_e = 600 \text{ A/mm}^2$ at 4.2 K and 20 T
- Angle dependence: worst case conditions
- Field dependence: Robinson Research Institute HTS Wire database, extrapolated to lower temperatures and higher flux densities
AMaSED-2 coil design

- Racetrack-like shape, size: 480 mm x 256 mm
- No-insulation coil, two HTS tapes (face-to-face)
- 724 m of 12 mm wide SuperPower HTS tape
- Theoretical maximum operating current: 2480 A at 4.2 K, and peak magnetic flux density of 9.3 T
- Stored energy: 143 kJ
- Inductance: 47 mH
- Central magnetic flux density: 2.8 T
AMaSED-2 coil configuration

Top view

Current lead

Outer copper band

Inner copper band

Copper layer jump

Cross sectional view

Inner copper band

Copper layer jump

Outer copper band
AMaSED-2 mechanical structure

Materials
- Aluminum 2050-T84
- G-11 (fiberglass)
- Kapton® HN (polyamide)
- Oxygen-Free Electronic Copper C10100
- AISI 316 stainless steel
- Ultem® 1000 (polyetherimide)
- Winding block

AMaSED-2
- Interconnection insulation cover
- Magnetic sensor holder
- Copper bands
- Interconnection block
- Current leads
- Magnet former
- Threaded inserts
- Insulation layer
- Coil shim
- Insulation shells
- Cover plate
- Bolts
AMaSED-2 mechanical analysis

Static structural
Equivalent (von-Mises) Stress
Deformation Scale Factor: 14

[MPa]

- 259
- 230
- 201
- 172
- 144
- 115
- 86
- 58
- 29
- 0

0 100 200 (mm)
Magnet manufacturing overview

The following coils have been built:

1) Small solenoids: Three configurations to test cable and solder configurations and charging/discharging behavior. Each coil uses 50-60 m of HTS tape.

2) AMaSED-0: Mechanical model coil using copper coated stainless steel tape instead of HTS tape. Cable consists of two identical tapes.

3) AMaSED-1: Single pancake practice coil using 380 m of THEVA HTS tape. Cable consists of a two-tape stack.

4) AMaSED-2: Final demonstrator coil using 724 m SuperPower HTS tape. Cable consists of a two-tape stack.
Small solenoids

1) Single HTS tape, non-insulated, non-soldered

2) Single HTS tape, non-insulated, soldered

3) Two HTS tapes, non-insulated, non-soldered
AMaSED-0
AMaSED-2
Summary of the HDMS project

Part 1: Conceptual design of the ARCOS magnet

- 12 racetrack-shaped coil packs
- Bending strength: 3 Tm, peak field: 11.9 T
- Lightweight aluminum structure

Part 2: Design and manufacture of AMaSED-2

- Small-scale version of a single coil pack of the ARCOS magnet
- No-insulation coil
- Status: AMaSED-2 has been manufactured, awaiting cold test