Structuring metallic coatings to reduce eddy currents and thermal noise in super insulation

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Abstract. The performance of multi-layered super insulation in cryogenic systems is highly dependent on the radiative properties of reflector foil surfaces. Aluminum coated polyester foils are utilized for their high reflectivity in the infrared spectrum. This coating is an electrical conductor and in applications with variable magnetic fields, eddy currents are induced in the coating. These eddy currents can have two effects. In high energy applications like for example superconducting fault current limiters, heat is dissipated in the super insulation, degrading its performance and potentially even damaging the super insulation. For high precision magnetic measurements utilizing SQUIDs, switching ambient fields induce eddy currents in the super insulation which result in a transient response superposing the signal to be measured. This, in addition to a higher thermal noise background reduces the quality of the magnetic measurements. Our study developed Coolcat 2 NI with a 10x10 mm grid in the metallic coating. In this way the high reflectivity provided by the aluminum has been retained and the eddy currents were reduced to a level acceptable for different applications. Calorimetric and magnetic experiments are presented to show the merits of this structuring.

1. Introduction
Polyester foils with vacuum deposited aluminum (VDA) are widely used in cryogenics to decrease the heat load on superconductors and cold masses. For some applications the continuous coating of the non conducting polyester with a conductor like aluminum causes problems. One can define two different applications with slightly different requirements.

Changing magnetic fields or rotating cold masses induce eddy currents in the aluminum and heat dissipated by these eddy currents may damage the super insulation like in superconducting Fault Current Limiter or other energy applications. Another application are high precision measurements utilizing SQUIDS, as ambient magnetic fields interact with the super insulation and lead to high background levels for the measurements. Our study therefore investigated various processes to structure the metallic coatings to address these issues. The aim was to retain the high reflectivity
provided by the aluminum and to reduce the eddy currents to a level acceptable for different applications.

The design of the foil parameter has to be a compromise between thermal and electrical properties. To test and evaluate these properties several calorimetric and magnetic experiments were conducted. Based on these the most effective structured coating was chosen.

2. Materials
A simulation with Comsol Multiphysics 4.3 shows that eddy currents get smaller with each division of the coating. The reduction of the eddy currents gets smaller with each additional division, so it was determined that at least 5-10 divisions per area would be best. Typical super insulation designs feature areas larger than 100 mm, so a pattern size of 10 mm x 10 mm was utilized.

Coolcat 2 NI (Non Inductive) is a spaced superinsulation composed of 10 layers of 12µm polyester foil, single-side aluminized in squares of 10 mm x 10 mm, interleaved with 10 layers of non-woven polyester spacer material. It is available with two different surface resistances, 0.8 Ohms per square and 1.6 Ohms per square. A lower surface resistance means that the aluminum coating is thicker. The distance between the squares is approximately 100 µm.

The foils used in Coolcat 2 NI were developed in a cooperation of the Vienna University of Technology and the Thermal Systems department of RUAG Space GmbH.

Details of the production technique are still confidential at this time, but the gaps in the aluminum were produced using a chemical release method. Before depositing the aluminum on the polyester by vacuum deposition, a chemical gets printed onto the foil in the desired pattern. This chemical is then later activated and the aluminum can be removed locally.

3. Magnetic field measurements
Magnetic thermal noise measurements were performed with 20 layers of structured foil interleaved with 20 layers of polyester spacer material, on a sample size of 100 mm × 100 mm. The measurements were conducted with a SQUID system inside a magnetically shielded room of the Physikalisch-Technische Bundesanstalt [1]. The SQUID current sensor, coupled to a first order axial gradiometer, baseline 120 mm and radius 20 mm, was operated in a low-noise dewar with a warm-cold distance of 8.8 mm (measured at room temperature) [2]. The stack was positioned centrally under the dewar bottom.

| Frequency [Hz] | Noise spectral density for SQUID system [fT/√Hz] | Noise spectral density for 0.8 Ohms per square [fT/√Hz] | Noise spectral density for 1.6 Ohms per square [fT/√Hz] |
|---------------|-----------------------------------------------|------------------------------------------------|------------------------------------------------|
| 40            | 2.30                                          | 2.68 (1.37)                                      | 2.60 (1.21)                                      |
| 100           | 2.06                                          | 2.39 (1.21)                                      | 2.40 (1.23)                                      |
| 500           | 1.65                                          | 2.03 (1.18)                                      | 2.06 (1.23)                                      |
| 1000          | 1.66                                          | 2.14 (1.35)                                      | 2.12 (1.32)                                      |
| 10000         | 1.48                                          | 1.89 (1.18)                                      | 1.80 (1.02)                                      |

The calculated noise contributions shown in Table 1 are very similar for both coating thicknesses. For SQUID Applications the noise contribution shall be as low as possible. A value in the range of 1-2 fT/√Hz is considered acceptable. Figure 1 shows the spectral noise density for both materials. The white noise contribution for the 0.8 Ohm/square and 1.6 Ohms/square samples for this geometry at room temperature are measured as 1.0 fT/√Hz and 1.1 fT/√Hz, respectively (from the noise spectra).
4. Calorimetric measurements

The emissivities of the different foils were measured and compared to a former material type, which is no longer available. In Figure 2 one can compare the emissivities of a continuously VDA coated foil, of the former patterned material and of the new 0.8 Ohms per square surface resistance patterned material utilized in Coolcat 2 NI. The emissivity of the new material is significantly better than the values of the former material. The measurements were performed by using a calorimeter as described in ref. [3].

**Figure 1.** Noise spectral density spectra for Coolcat 2 NI, with 0.8 and 1.6 Ohm/square coating; the contribution without SQUID background levels is shown individually.

**Figure 2.** Emissivity single foil layer.
In Table 2 we summarize the results of calorimetric measurements on Coolcat 2 NI MLI blankets performed at THISTA, Karlsruhe Institute of Technology (KIT) [4].

| Temperature range [K] | Number of layers | Heat flux [W/m²] |
|-----------------------|------------------|-----------------|
| 300 to 77             | 10 foils + 10 spacers | > 4.60          |
|                       | 20 foils + 20 spacers     | > 3.40          |

5. Conclusion
The work provided a new material for application in SQUIDs and high energy superconducting applications to reduce eddy currents and magnetic background noise in super insulation. The thermal performance was improved compared to state of the art materials and important properties of the materials were tested with application in superconducting fault current limiters, superconducting generators, superconducting motors and SQUIDs in mind. Coolcat 2 NI has a white noise contribution of 1.0 fT/√Hz and reduces the heat flux from 300 to 77 K to approximately 4 W/m².

6. Acknowledgements
Coolcat 2 NI was developed in a cooperation of the Vienna University of Technology and the Thermal Systems department of RUAG Space GmbH. The authors thank RUAG Space GmbH to let them use available state-of-the-art equipment and analyses tools, clean rooms and automated cutting machines.

The authors acknowledge support from RUAG Space GmbH and the Austrian Federal Ministry of Transport, Innovation and Technology (Austrian Research Promotion Agency).

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