Contribution ID: **501** Type: **Invited Oral**

M3Or4B-02: [Invited] Composite materials for electrical insulation of superconducting coils

Wednesday 21 May 2025 16:40 (25 minutes)

Research on high-field magnets has always been instrumental for high energy colliders. Amongst many aspects in magnet design and construction, the electrical insulation system is of paramount importance to ensure required performance. Concerning the manufacturing of Nb3Sn magnets, superconducting coils undergo a vacuum impregnation process which requires the impregnation system to have a low viscosity and high processing time. The typical cable insulation process involves braiding a layer of mineral fibre, commonly S-glass onto Rutherford cables, which are subsequently wound into coils, reacted at high temperatures to form the superconducting phase, and vacuum-impregnated with epoxy resin. During operation, superconducting magnets as well as their insulation systems are exposed to cryogenic temperature, high radiation levels and mechanical loads.

This presentation aims to give an overview of the advancements in composite materials and the parameters to consider when selecting an electrical insulation for superconducting coils to fit the magnet requirements with adequate margin. The first aspect concerns the investigation of polymer matrices, starting from their chemistries, followed by the study of their process, physico-chemical and electrical properties to their mechanical properties. The end properties of the composites are greatly influenced by several parameters such as the toughness or the radiation hardness of polymers, properties directly linked to their chemistries. To evaluate their properties after irradiation, many test campaigns were implemented to reproduce real ageing conditions in superconducting magnets, through different irradiations sources, environments and temperatures. This screening includes the most used epoxy resin systems for impregnation of superconducting coils among the stakeholders of the domain.

The second aspect to consider is the fibre reinforcements. These fibres have different functions, such as providing mechanical support to the coils to withstand Lorentz forces while in operation or serving as spacers between cables for electrical insulation. A sizing is required on those fibres for handling during braiding or increasing the matrix/fibre adhesion. However, Nb3Sn coils need to be reacted at a peak temperature of typically 650 ℃ to create the superconducting phase and this directly degrades the sizing, leaving conductive residues before impregnation, hence impacting negatively the electrical insulation properties. Thus, this second part investigates strategies to enhance cable insulation robustness, focusing on the selection of high-performance fibres, optimization of braiding layouts, and the refinement of de-sizing processes to improve fibre-resin compatibility and electrical performances. Robustness is assessed using electrical testing, including resistivity and voltage withstand tests.

Finally, the combination of polymer matrices and fibre reinforcements, i.e. composite materials are addressed. This starts with the manufacturing process, applied at different scales including the study of the process parameters, followed by the investigation of their mechanical and electrical properties, towards the manufacturing of real magnet prototypes tested at cold.

Overall, this work aims to provide insights about the choice of composite materials depending on the desired properties and type of magnet targeted, to meet the stringent demands of next-generation superconducting magnets, contributing to advancements in particle accelerator technologies.

Author: SCHENK, Vincent

Co-authors: SCHEUERLEIN, Christian (CERN); PICCIN, Roland (CERN)

Presenter: SCHENK, Vincent

Session Classification: M3Or4B - [Special Session] Materials for High Field Magnets