REPAIR AND IMPROVEMENT OF THE SUPERCONDUCTING MAGNETS OF THE S^3 SPECTROMETER AT GANIL

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Abstract

In order to achieve optimal performance in terms of transmission and separation for the S^3 spectrometer, the project chose to design superconducting magnets integrating 11 magnetic functions in a single cryostat. There are seven of these magnets, called Superconducting Multipole Triplets, in the spectrometer. The compactness of these magnets makes them remarkable and unique, but has led to significant commissioning difficulties. As the design was very close to the acceptable operating limits, we experienced several breakages and leaks, as well as limitations in terms of nominal current. In this presentation, we will show the important work we carried out to repair the main conductor, improve the robustness of the current leads and feedthrough, and repair the various leaks.

SUPER SEPARATOR SPECTROMETER

S^3 spectrometer sorts elements by mass/energy and deliver a high intensity beam of highly curated heavy ions. To achieve this great feat, it uses seven Superconductor Magnetic Triplet to drive the particles beam through hot magnet, beam dumps, electrostatic dipole and beam characterization devices.

SUPERCONDUCTING MAGNETIC TRIPLET

SMT Characteristics

SMT (Fig. 1) are cryogenically cooled magnet divided in three sections:

- Twelve magnetic fields in total. Each singlet embedding bipolar, quadripolar, sextupolar and octupolar coils.
- 16 Current lines to feed up to 450 Amps coils / 48 current feedthrough.
- Use liquid Nitrogen to cool and shield the liquid Helium tank.
- Cold mass is suspended around an Ø360mm beam chamber.
- Weight 3 metric tons, measure 1.8 m high, 1.8 m long.
- Superconductor coils protected by high sensitivity voltage monitors.

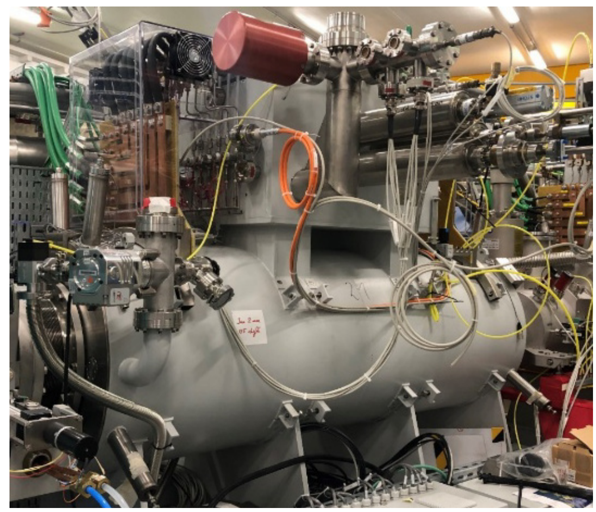

Figure 1: SMT set-up on beam line.

HTS CURRENT LEAD REPAIR

The High temperature Superconductor current lead (Fig. 2) feed electrical current from the « warm » side (liquid Nitrogen) to the « cold » part (liquid Helium). This constructor development is made of two part. the top section transfer current from copper lead (80 K), through a DI-BSCCO type G tape (Tc 108 K) and the lower part is an addition of YBCO flexible tapes (Tc 93 K). We mostly had to deal with delamination on the YBCO part, likely due to ripping effect of mechanical stress and sudden high current flux. Since 2022, we practiced more than 80 HTS current lead changes, refining tools and methods. We mostly use IN/SN soft solder with Tixflux but also pure Indium sheet strongly clamped. It is important to limit HTS current lead heat exposure and we cool them abundantly after soldering with compressed air and isopropanol. IRFU of DACM helped us in defining a new generation of ReBCO current lead in order to achieve high degree of reliability and manage spare parts availability.

Figure 2: HTS lead assembly. YBCO tapes on the left, BiSCCO rod on the right.

LTS WIRE REPAIR

The LTS (Low Temperature Superconductor) current lead part connect the HTS lower feedthrough to the magnet pins in the liquid Helium tank (4 K). It is made of copper encapsulating Niobium/Titanium filaments (Tc 9.2 K). In October 2022, we face a sudden break during current ramping up (60 A). After multiple localization test (Fig. 3), we identified the burned part and GANIL took the opportunity to repair in-house.

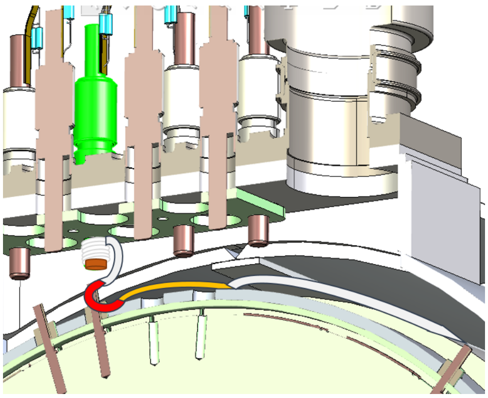

Figure 3: LTS break localisation.

Electricians, Mechanics, Vacuum and Cryogenic teams had to collaborate closely in order to open, fix, test and close the SMT. LEAS department of IRFU helped us to better understand how to manage such material and provided some LTS wires (Fig.4).

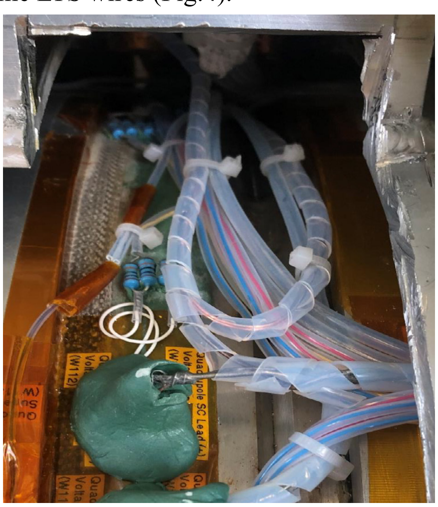

Figure 4: LTS solder repair.

They also helped us to understand we face a cooling issue in the upper part of the Helium tank and we missed proper transition monitoring of those wires. We decided to completely rearrange the surveillance cabinet of the 7 SMT and worked on a better cooling strategy and instrumentation.

HELIUM GAUGE ADDITION

The LTS breakage lead us to think we missed cooling in the LTS connection upper area. The original gauge is sufficient to cool the cold mass encapsulating coils. We proposed an addition of a liquid Helium gauge, set up above the original. The goal is regulate the cryogenic coolant at higher level. IJClab cryogenic specialists validated our solution, and made extra recommendations. We use custom made superconductor gauges (Ø6.33 x 125.5 mm) placed in the signals and evacuation chimney (100mm active length) with a Model 1700 level transmitter from American Magnetic Inc. We designed our own articulated gauges holder set on a CF40 flange (Fig. 5).

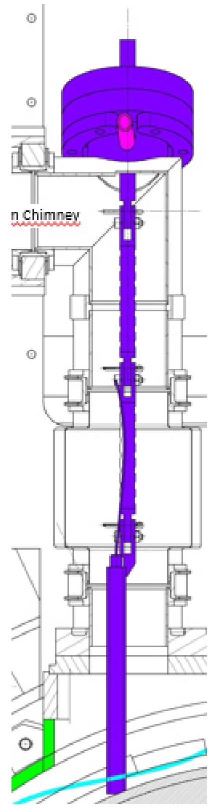

Figure 5: Helium gauge holder assembly.

And we add a drain from the chimney, leading to the Helium return circuit, thus preventing pressure build up and easing cryogenic flow (Fig. 6).

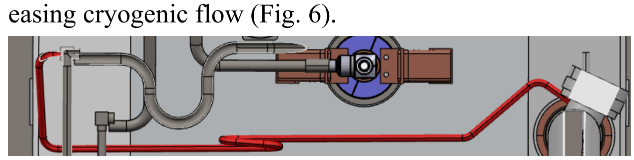

Figure 6: Helium drain addition.

Four SMT out of seven have already been equipped and we await test in real condition. We aim to fill the tank near its top, in order to cool efficiently LTS wires and copper feedthrough. It should prevent superconductor transition and breakage.

CURRENT FEEDTHROUGH REPLACEMENT

The copper current feedthrough are made to carry high electrical intensity isolated from the stainless steel enclosure, while keeping an hermetic separation at each side, even in cryogenic and vacuum environment. When the first leaks appeared coming from the liquid nitrogen reservoir, we run overhaul checks and found out many oxidized feedthrough (Fig. 7).

Figure 7: Oxidation.

We identify solder flux pollutions as precursor coupled with water/oxygen on cold surfaces to be the cause of this corrosion. We have to change four SMT set of feedthrough (16 each) by performing openings from the top side and removal of HTS on the bottom end. It allowed us to design our own coupling parts from the raw on-shelf products (Fig. 8).

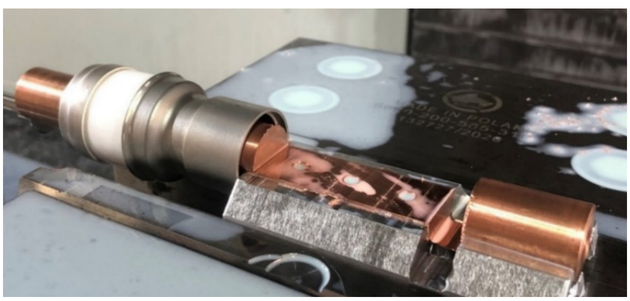

Figure 8: In-house machined feedthrough.

Instead of soft solder and screw mechanism, we now use indium sheet, bolts and protection measures such as dry nitrogen filling to insure the longevity of the overall system. The one made to repair the LTS wire from the Helium tank had to more specific (Fig. 9). We made it longer, shaped it to receive the wire and fit the cramped area. Each one of the HTS replacement in their upper side has to be done with In52/Sn48 (118°C) and great cooling to prevent melting of the lower section done with Sn60/Pb40 solder (183°C).

Figure 9: LTS wiring on specific machined feedthrough.

SEALING AND WELDING OF CRYOGENIC TANKS

Each openings in the cryostat, had to be carefully planned and executed in order to be able to close it after. The top 19 mm stainless steel plate was fully machined to receive a 7 mm elastomer joint for atmospheric isolation. Two openings per Nitrogen tank were performed in the aluminium enclosure. The process of sealing this pressurized, cryogenically cooled box in vacuum drove several iteration and test. First a 5mm Indium wire, then two 1mm Indium threads on a frame, and now a custom made aluminium knife edge join. We use ventilated screw to prevent virtual leaks and specific Belleville washers to keep plates firmly held onto the Nitrogen enclosure. The most difficult part is the 6mm aluminium TIG welding of the liquid Helium tank closure (Fig. 10). To achieve perfect sealing on a large cylinder cooled at 4 K in vacuum is no small feat. While protecting electrical connection 10mm away and not burning the Multi-Layer Insulation tightly set around the cryostat. Extensive preparation, tests and ultrasonic quality control is being carried out by our welding team to achieve this goal.

Figure 10: Aluminium tank TIG welding.

DEDICATED TEAM WORK

Superconductor magnets are new to our lab and we didn't expect to dive into its functioning. We faced gradually difficult repair task and we took the opportunity to learn from it. LTS repair was a big challenge and a learning accelerator. The necessary team work allowed each specialist to develop their own ingenious process and delicate technical solution. I want to address special thanks to people who addressed those difficult tasks and still carries it through.