DEVELOPMENT AND VALIDATION OF A FAST CRYOCOOLER MAINTENANCE SYSTEM

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Abstract

At IBA, we have been developing and testing new systems to simplify cryocooler maintenance at a minimal cost (material, interruption of service). A local heating system has been designed to heat-up both stages of a cryocooler to room temperature while keeping the cold mass at a low temperature. The heating system has to fulfill severe requirements such as high power density, compatibility with vacuum and low temperature, and easy operation. The whole system has been designed and tested in a dedicated test bench and then duplicated onto a full-size superconducting coil. It has been extensively tested under different conditions to prove that the heating system is robust and reliable and has no impact on the superconducting coil performances.

INTRODUCTION

The basic principle of the developed system for maintenance relies on a patent that dates back to the 90's [1]. It consists in performing a quick local heating of the cryocoolers to room temperature while keeping the cold mass as cold as possible. This method, also known as cold swap, requires that the cryogenic system and the heating system can support the mechanical stress induced by the large temperature gradient that will occur during the heating operation.

A preliminary study had demonstrated that the required heating power to reach room temperature in our superconducting coil in 20 minutes was 1kW for a cryocooler second stage and 500W for a first stage [2]. Given the available space in the cryostat, high power density resistors are required. They also have to be vacuum and cryogenics compatible and be robust and reliable over more than 20 years. Finally, the heat load due to all the wiring must be compatible with the available cooling power.

DEDICATED TEST BENCH

A dedicated test bench has been designed and used to test the different components of the heating system (Fig. 1). The turbo pump allows to reach a good vacuum level in the chamber in 3 h. A small aluminium thermal mass has been attached to the second stage of a Sumitomo RDK415D2 cryocooler (Fig. 2) and it takes another 4 h to reach the final temperature of 6.3 K without the use of any superinsulation. Each stage cryohead was equipped with one Cernox and one Pt100 per stage to monitor the temperature. Several vacuum feedthroughs allow us to monitor each stage temperature and also to control and monitor separately each heater resistor. A LabVIEW™ program has been developed to record the temperatures, pressure and also to control the two power supplies for the first and second stage separately.

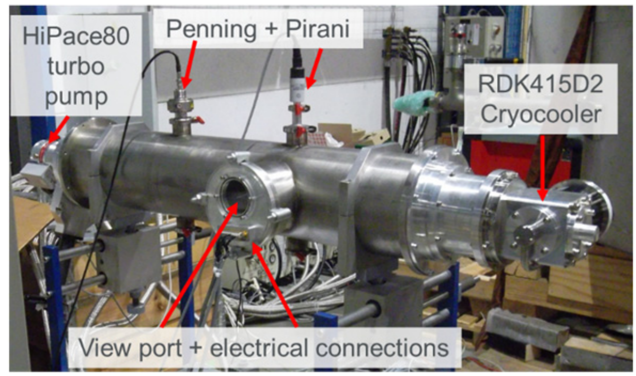

Figure 1: Dedicated test bench.

This test bench allows us to iterate rapidly on the design of the heaters and their wiring to make them robust, safe and reliable. The heating resistors have been tested extensively for vacuum and cryogenic compatibility, reliability after several tens of cycles between 4 K and room temperature. Destructive tests were also performed to check the robustness of the resistors and their safe operation condition. Thermal anchoring of all the wiring was also very important to avoid local hot spot and reduce the heat load to the second stage where only a few watts are available at 4 K. The full heating system (for 1st and 2nd stage) for a single cryocooler head has been designed, tested and validated on this test bench.

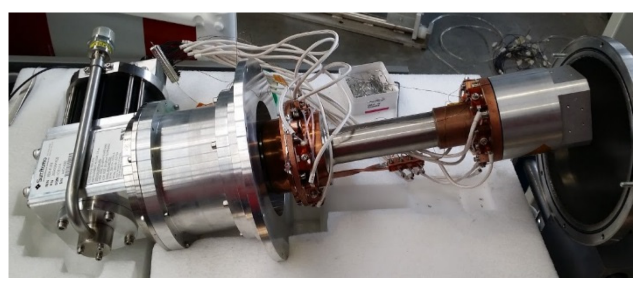

Figure 2: 1st and 2nd stage heating system.

INTEGRATION IN A SUPERCONDUCTING COIL

Proof of Concept of the Cold Swap Maintenance

As soon as the heating system was validated, it was reproduced for the four cryoheads of a R&D superconducting coil. The objective was to validate the required heating power and to evaluate the maximum temperature reached by the cold mass and hence the subsequent cooling time.

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For redundancy reason, a total heating power of 2 kW was installed on each of the four second stages and 1.5 kW on the first ones. A Cernox and a Pt100 on each of the first and second stages assure the redundancy for the temperature measurement.

After the integration of the heating system in the superconducting coil, the magnet was cooled down. All the temperatures within the coil were carefully monitored to assess the impact of the heat load of the heating system. It has been observed that neither the cool down time nor the final temperature were impacted by the heating system.

The heating system was then used to warm-up locally each of the four cryocoolers successively. The upper cryoheads were maintained at room temperature during 30 minutes and the lower ones during 40 minutes, corresponding to the time to perform the cryohead servicing. Only one cryohead was really maintained, the other three were only heated to simulate maintenance but the cryoheads were not serviced. The maximal temperature at the end of this process was 65 K. On this coil, the cooldown time to recover 4 K was 35 h. It is then possible to perform the maintenance of the four cryohead of a superconducting coil using the cold swap method over a weekend.

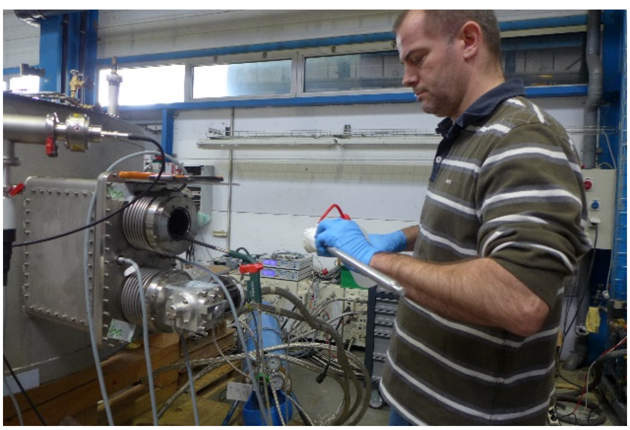

Figure 3: Cryohead maintenance with the cold swap method.

Impact on the Magnet Performances and Structure

The full system was then integrated in a production coil whose mechanical design is slightly different from the R&D one. The objective was to evaluate the impact of any mechanical stress introduced by the heating process on the magnet performance and magnet structure integrity. Indeed, the cold swap method imposes to have large temperature gradient inside the superconducting coil during the maintenance operation.

Again, neither the superconducting coil cool down time nor final temperature were impacted by the added heating system. The superconducting coil acceptance tests (nominal field, test quench, fast ramp-up) were rerun successfully without any impact on the coil performances.

After that, the following cycling sequence was executed:

1. For each of the four cryohead, heat-up the 1st and the 2nd stage to room temperature and maintain 300 K for 30 minutes to simulate the maintenance operation (4.5 h in total);
2. Cool down the magnet to 4 K (~30 h);
3. Check the heater resistances value and electrical insulation.
4. Ramp-up the magnetic field to nominal current (4 h);
5. Ramp-down the magnetic field.
6. Check the heater resistances value and electrical insulation.

All the superconducting coil properties (coil temperature, pressure, tie-rods forces, voltage taps, …) were recorded by the magnet control system. A separate LabVIEW™ program was developed to regulate and record the heating system power and monitor the thermometers used for the cryohead maintenance.

In total, eight cycles were performed. All the cycles were highly reproducible in term of maximal temperature after heat-up, cooldown time, nominal temperature after cooldown, maximum temperature during magnet ramp-up. The heaters resistance and insulation tests were also highly reproducible indicating a high stability, reliability and robustness of the heating system. The analysis of the forces on the tie-rods also shows that the heating process tends to release the forces in the superconducting coil.

CONCLUSIONS

The cold swap method has proven to allow for a maintenance while keeping the cold mass of the superconducting coil at a maximum of 65 K. The time to recover the magnet nominal temperature allows for a maintenance over a weekend. The coil performances (nominal temperature, ramp-up time) are not impacted by the heating system. Also, the heat-up tends to release the forces in the coil without impacting the structure of the superconducting coil. This system is now implemented in every superconducting coil.

ACKNOWLEDGEMENT

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