

THE INTERCONNECTIONS OF THE LHC CRYOMAGNETS

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Abstract

The main components of the LHC, the next world-class facility in high-energy physics, are the twin-aperture high-field superconducting cryomagnets to be installed in the existing 26.7-km long tunnel. After installation and alignment, the cryomagnets have to be interconnected. The interconnections must ensure the continuity of several functions: vacuum enclosures, beam pipe image currents (RF contacts), cryogenic circuits, electrical power supply, and thermal insulation.

In the machine, about 1700 interconnections between cryomagnets are necessary. The interconnections constitute a unique system that is nearly entirely assembled in the tunnel. For each of them, various operations must be done: TIG welding of cryogenic channels ($\approx 50\,000$ welds), induction soldering of main superconducting cables ($\approx 10\,000$ joints), ultrasonic welding of auxiliary superconducting cables ($\approx 20\,000$ welds), mechanical assembly of various elements, and installation of the multi-layer insulation ($\approx 200\,000\text{ m}^2$). Defective junctions could be very difficult and expensive to detect and repair. Reproducible and reliable processes must be implemented together with a strict quality control.

The interconnection activities are optimized taking into account several constraints: limited space availability, tight installation schedule, high level of quality, high reliability and economical aspects.

In this paper, the functions to be fulfilled by the interconnections and the various technologies selected are presented. Quality control at different levels (component/interconnect, subsystem, system) is also described. The interconnection assembly sequences are summarized. Finally, the validation of the interconnection procedures is presented, based in particular on the LHC prototype cell assembly (STRING2).

1 INTRODUCTION

The interconnections of the twin-aperture high-field superconducting cryomagnets will be carried out in the tunnel. They must ensure the continuity of several functions: vacuum enclosures, beam pipes, beam screen image currents (RF contacts), cryogenic circuits, electrical power supply, thermal insulation, etc. For the whole LHC machine, about 1700 interconnections between cryomagnets have to be carried out. Every 108 m, the chain of superconducting magnets is connected to the cryogenic distribution line by so called "jumpers". The continuity of vacuum enclosures, cryogenic circuits and thermal insulation must be ensured through the jumpers. The two basic types of interconnection may be seen in Fig. 1.

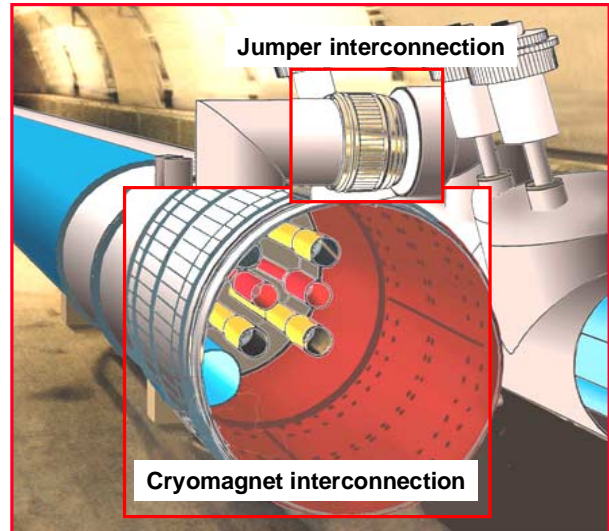


Figure 1: 3D view of the interconnections.

2 JOINING TECHNOLOGIES

In this chapter, the specific technologies used to assemble the LHC interconnection are described. They have to meet some general requirements:

- Limited space (longitudinally and radially).
- High reliability and quality.
- Economical and schedule constraints.

2.1 Induction Soldering

The main magnets are powered by Niobium/Titanium superconducting cables, carrying up to 13 000 A. Inside each magnet-to-magnet interconnection, six cables of this type must be joined. The main constraints and requirements applying to them are:

- High number of joints (about 10 000).
- High current intensity (up to 13 000 A).
- Low electrical resistance ($< 0.6\text{ n}\Omega$ to meet the requirements of the cryogenic budget).

Induction soldering was selected to perform a reliable junction of the main bus bars and to achieve a low electrical resistance at cold. To preserve the superconducting properties of the cables, the temperature and heating time have to be limited. Inductive heating permits a heating time of only about 90 seconds between 223 °C and 230 °C. A non-corrosive flux was selected after intensive testing: mechanical, electrical, corrosion. To ensure a good quality of the soldered joint, the cable extremities must be in good condition (cleanliness, dimensional accuracy), and stabilized (pre-tinned) beforehand. This technology is giving very good results and has been used for STRING2 interconnections [1]. An attempt is presently made to render the process independent of the operator (closed loop control).

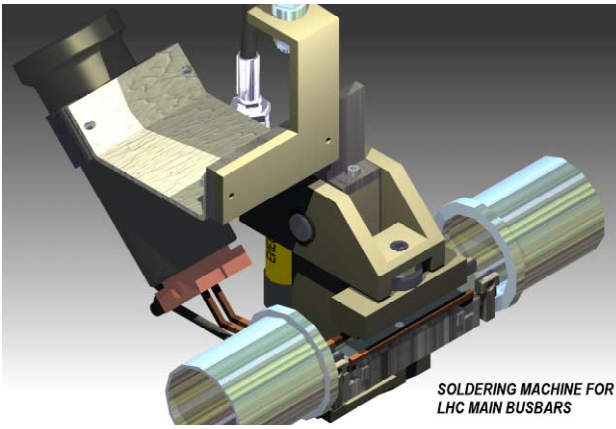


Figure 2: Induction soldering machine.

2.2 Ultrasonic Welding

This technology was developed in collaboration with LAPP (Laboratoire d'Annecy de Physique des Particules) to perform the junction of the auxiliary bus bars, [2]. The main constraints and requirements are:

- High number of joints (more than 50 000).
- Current intensity (up to 600 A).
- Low electrical resistance ($< 18 \text{ n}\Omega$ to meet the requirements of the cryogenic budget).

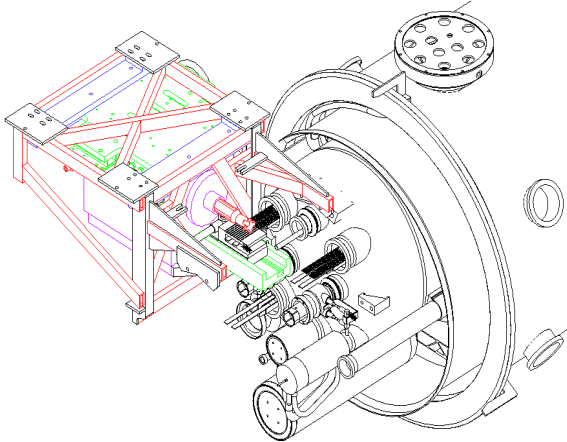


Figure 3: Ultrasonic welding machine.

The quality of the process is controlled by on-line recording of operating parameters such as power, driving in, time, dissipated energy. This technology was also applied for STRING2 and is giving very good results [1]. The average electrical resistance achieved is about $3 \text{ n}\Omega$.

2.3 TIG Welding

The very high number of welds (about 50 000) to be performed in a very limited radial clearance of 45 mm requires a very reliable process.

The choice of TIG welding together with the automatic orbital machines associated with a specific geometry of the welds meets all these requirements. To ensure the reproducibility and quality, the on-line recording of the welding parameters (voltage, intensity, etc.) is foreseen.

2.4 Orbital Cutting

For testing and preparation activities, it is necessary to cut stainless steel pipes. Because of the very strict space

constraints, it was necessary to accommodate the automatic orbital cutting machines with a 45 mm clearance. This technology could also be used for possible repair or upgrading activities.

3 THE INTERCONNECTION ACTIVITIES

3.1 The Interconnection Assembly Sequences

The sequence of operations necessary to carry out an interconnection has been defined following some general principles:

- From inside (beam lines) towards outside (vacuum vessel sleeve) for ease of work.
- Operations involving fragile components are carried out as late as possible.
- Whenever possible, operations requiring the same tooling are performed consecutively.
- The most delicate parts are protected (bellows, bus bars extremities, etc.).
- At some points, permission of those responsible for relevant systems is mandatory to go ahead.

3.2 Interconnections between Cryomagnets

After cold test and preparation for installation in the tunnel, the cryomagnets are transported in the tunnel and aligned. Then, the interconnection activities can start.

1. The RF modules are mounted. They provide smooth electrical continuity between adjacent beam screens [3]. They are TIG welded in-situ. (Fig. 4)

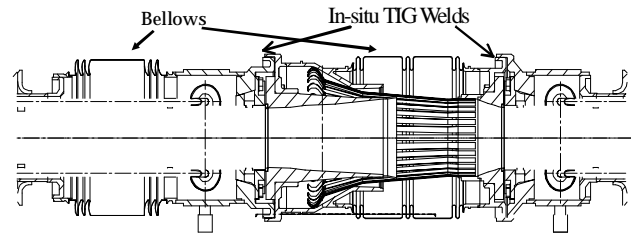


Figure 4: Beam lines interconnection.

2. The soldering of the six main bus bars is performed, applying the technology described in section 2.1. The electrical insulation is rebuilt. The 20 spool-piece bus bars are ultrasonically welded (see section 2.2).
3. An important electrical verification is performed. The main functions to check are: electrical continuity of circuits, electrical insulation (voltage withstand levels) and conformity to the electrical scheme.
4. The sleeves closing the cryogenic channels are slid in place and TIG welded.
5. The two heat exchanger lines are connected. The inner copper tube is soldered using a non-aggressive flux and the outer stainless steel sleeve is welded.
6. The support post cooling line is interconnected. This system is auto-stabilized thanks to compensation loops present at both sides.
7. The thermal shield is cooled by gaseous Helium [50 K to 65 K]. The interconnection is realized by TIG welding of the expansion joint (Fig. 5).

