DESIGN OF AN AUTOMATIC SYSTEM FOR THE ELECTRICAL QUALITY ASSURANCE DURING THE ASSEMBLY OF THE ELECTRICAL CIRCUITS OF THE LHC

D. Bozzini, V. Chareyre, A. Jacob, K.H. Mess, S. Russenschuck, R. Solaz-Cerdan,
CERN, Geneva, Switzerland

Abstract

A method has been developed to verify automatically in the LHC tunnel the correct wiring of the 1712 circuits with about 70000 splices for the powering of all-together 10094 magnet units in the LHC machine. The test equipment first detects the continuity of a part of the electrical circuit and then verifies the polarity and type of the magnets connected in the circuit. A 108-meter LHC cell is the shortest unit that can be tested. The mobile system is composed of a unit placed at the centre of the cell and two de-multiplexers positioned at the extremities of the cell. The central unit contains a data acquisition system with a high precision digital multi-meter (DMM), switching matrixes and digital I/O ports to drive the de-multiplexers. In total 217 signals can be acquired and 3160 voltage combinations are possible. Pointing to different databases, a LabVIEW program automatically executes the test procedure and then generates and stores the reports. The hardware and software design, the data flow between databases, and the testing methodology applied to the different circuit types are described.

INTRODUCTION

The Large Hadron Collider (LHC), presently under construction at CERN will bring into collision intense proton beams with a centre of mass energy of 14 TeV and a nominal luminosity of 10^{34} $cm^{-2}s^{-1}$. The magnet system required for this performance consists of 10094 superconducting magnet units, most of which are operated at 1.9 K. During the assembly of the LHC machine one of the challenges will be the correct wiring of the 1712 circuits with about 70000 splices for the powering of the magnet units. At each interconnection plane between two cryo-magnet assemblies, up to 72 junctions will be performed on electrical circuits with a current rating between 600 A and 13 kA. Considering the complexity of the electrical scheme, there is a considerable risk of wiring faults which will perturb LHC operation if they are not detected during the assembly phase in the tunnel. One of the most complex circuits is composed of 154 sextupole corrector magnets distributed along the full length of an entire arc composed of 23 cells. Any electrical fault not detected during the assembly in the tunnel will be hardly discernible when the machine is at cryogenic conditions. As a consequence, repairs will be costly and time consuming. In order to ensure the proper assembly and functioning of the LHC machine, an electrical quality assurance (ELQA) plan [1] has been established. This paper describes the design of an automatic system for the ELQA activities to be applied during the assembly of the arc and dispersion suppressor zones of the LHC machine.

METHODOLOGY OF VERIFICATION

Electrical powering layout

The LHC machine layout comprises eight arcs and sixteen dispersion suppressor zones. The continuous cryostat includes one arc zone and two dispersion suppressor zones at each extremity, with a total length of 2.7 km. Six main bus-bars are used for the powering of the main dipoles and the quadrupole circuits rated for 13 kA. 20 auxiliary bus-bars rated for 600 A supply the spool-piece correctors of the main dipole magnets. These 26 bus-bars will be joined at each interconnection plane between two cryo-magnets. Further a cable with 42 auxiliary bus-bars feeds the corrector magnets associated with the main quadrupoles housed in the so-called short straight sections (SSS). The bus-bar cable is routed through the so-called line-N located outside the main magnet cold masses. Junctions of line-N cable segments will be made at each interconnection between a cryo-dipole and a SSS [2]. The polarity of a magnet can be checked by means of voltage taps connected to the lead A of the magnet units. All the signals from the voltage taps are routed out of the cold mass locally via an instrumentation feedthrough system [3]. Fig. 1 shows the electrical routing of the bus-bars along an LHC cell.

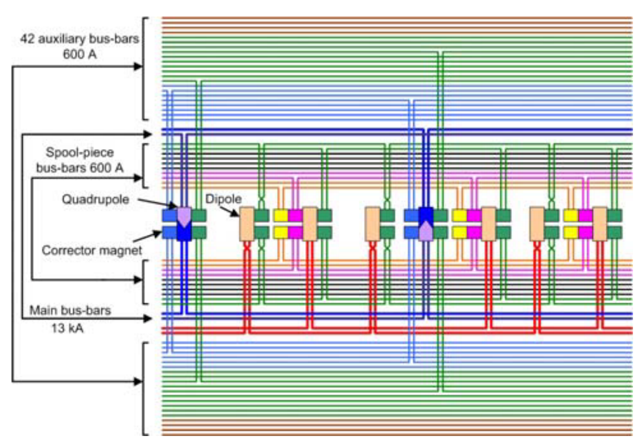

Figure 1: Electrical powering diagram of one LHC cell.

Parameters to be verified

To ensure the correct connection of bus-bars and in order to guarantee the right polarity of magnets powered in series, the following parameters are verified:

- Continuity of bus-bars and magnet interconnections.
- Authentication of magnet type by means of its measured ohmic resistance.
- Magnet polarity via the voltage taps on lead A.

Test procedures

The methodology applied for the continuity verification consists of feeding a stable DC current into a branch of the tested circuit. Voltage drops across precision resistors connected in series at both extremities of the branch confirm its continuity. The authentication and polarity of magnets connected in series within the branch are verified by measuring differential voltage drops between voltage taps at the magnet's lead A and the source and sink ends of the branch. The voltage measurements are automatically compared to known parameters stored in a database. In order to define a systematic method for the verification of the 70000 splices all different electrical interconnection types and corresponding configurations have been determined by analysing the data in the LHC reference database [4]. This analysis lead to the definition of 5 interconnection types in the line-N circuits, 6 types for the circuits of the spool-pieces in the arc zone and 6 types for the circuits of the spool-pieces in the dispersion suppressor region. A test procedure has been developed and implemented for each interconnection type allowing its automatic verification.

For the verification of the 42 auxiliary bus-bars in line-N, the access to three successive interconnection planes is required at the level of the so-called line-N interconnection board [5]. Fig. 2 shows the scheme for the verification of a magnet powered from the 42 auxiliary bus-bars cable. First the continuity of the circuit is assured by measuring voltage drops across the current reading resistors. Measured voltage drops between the allocated wire slots on the central interconnection board and the source and sink ends indicate the correct distribution of the wires. Finally the polarity and the type of the connected magnet are checked by measuring the expected voltage between the voltage tap attached to the magnet and the sink end.

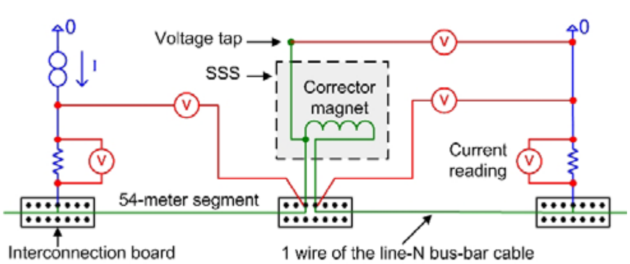

Figure 2: Example of the verification of a circuit branch for the powering of corrector magnets from the line-N.

The verification of the auxiliary spool-piece bus-bars only requires the access to the extremities of a cell. Fig. 3 shows an example of the scheme for the verification of two sextupole spool-piece magnets attached to the main dipoles.

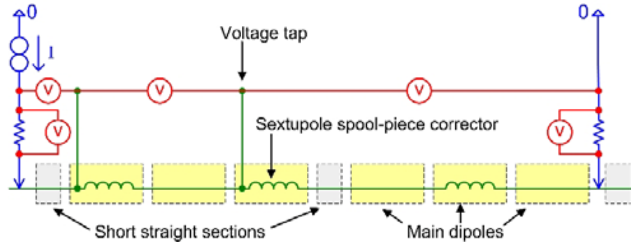

Figure 3: Verification of the connection of two sextupole correctors powered via an auxiliary spool-piece cable.

TECHNICAL DESIGN

The design of a mobile system for the circuit verification in the LHC tunnel has been launched with the following technical and environmental constraints: 1) Verification of a full cell. 2) Qualification of all types of interconnections with a tool which can be independently operated by two persons. 3) Hardware optimised for tunnel dimensions and storage underneath the cryo-magnets. 4) Fast connection of cables and connectors. 5) Software for the automatic validation of measured data with respect to the LHC reference database.

The mobile system

The mobile system is composed of a central unit to be placed at the centre of the cell including a portable computer running the software application, of two de-multiplexers positioned at the extremities of the cell, and the connectors and cables for the pick-up, routing and dispatching of the measurement and control signals.

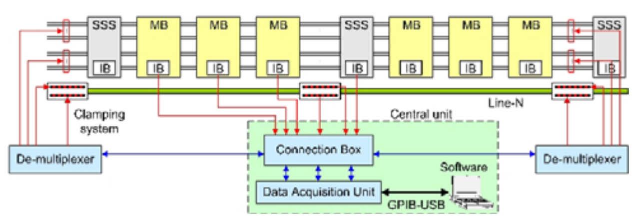

Figure 4: Layout of the mobile system.

The required signals dispersed along the 108 m long cell are collected in a connection box. All bus-bar signals are picked-up by connectors especially developed to ensure a fast plug-in and a reliable electrical contact. At the extremities of the cell two relay-based de-multiplexers allow the selection of a couple of signals, among the 70 available bus-bars. The selection of the required channel is done via 6 digital lines driven from the central unit. A cable containing the current readings and the digital lines links the de-multiplexer to the connection box. The signals coming from the central line-N interconnection board are directly routed to the connection box of the central unit. The voltage tap signals needed for the polarity checks are routed from each cryo-magnet instrumentation interface box [3] to the connection box via four dedicated cables.

The data acquisition system

The central unit contains a data acquisition system including a high precision DMM, two switching matrixes allowing the independent reading of the 3160 voltage combinations generated from the 217 signals gathered along the cell, and an I/O card for the control of the whole system. In total sixteen digital output lines are used in a sink mode to provide the control of the two de-multiplexers. Five analog channels are used. Four provide the current reading and the fifth allows for the differential voltage reading of two signals out of the 3160 combinations. The system is controlled by a LabVIEW based program with a GPIB Universal Serial Bus (USB) interface using the standard protocol IEEE 488.2. The system allows fully automatic verification and it is adapted to any configuration of the electrical circuit under test.

Management and transfer of data

The control of the system is based on the LabVIEW application and an Oracle database containing the information needed to perform the electrical qualification and allowing the storage of the test results. Fig. 5 shows the structure for the management and transfer of data.

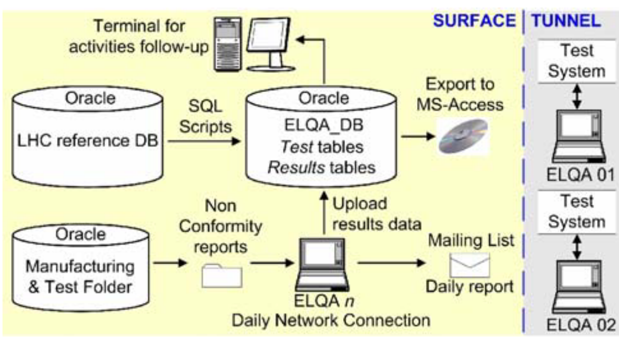

Figure 5: Flow and management of data.

The ELQA_DB database contains two parts, one containing the test tables and one containing the results tables. The test tables have been automatically generated by applying a package of PL/SQL scripts to the LHC reference database [4]. This ensures that the latest version of the LHC machine parameters is used. The generated database contains all electrical interconnection data necessary to perform and validate the electrical verification. The Oracle database is duplicated into a MS-Access format which can be exploited on portable computers, in order to have a self-sufficient test system in the LHC tunnel.

The procedure to verify a cell starts with the download of all the existing non conformity reports from the LHC Manufacturing and Test Folder [6]. Then, during the verification, the LabVIEW application points to the MS-Access database and automatically launches the tests for the particular cell to be verified. The measurement results are stored in the local database and a test report is locally generated. The collected information will afterwards be uploaded on the surface to the Oracle database for future processing. The test reports are automatically distributed to a mailing list.

The LabVIEW application includes useful tools for easing the verification activities in the tunnel, e.g., the automatic calibration of the hardware and the manual diagnostic of faults. In the presence of non conformities the baseline parameters and criteria for the qualification of a cell can be modified by authorized specialists. For the follow up of the activities, specific LabVIEW applications pointing directly to the Oracle database allow to retrieve any type of acquired data and provide for a graphical user interface to coordinate the test teams following the up to six installation fronts in the tunnel.

Test bench and surface training

A test bench has been developed allowing the reproduction of any of the LHC cell electrical configurations. This system was essential for the validation of the test equipment as well as for the definition of the test procedures. It will serve for off-line diagnostic and simulation of particular faults and configurations and will be extensively exploited for the training program of the crews assigned to perform the verification in the tunnel.

CONCLUSION

The hard and software for the electrical quality assurance during assembly of the arcs of the LHC machine has been designed and validated. The equipment and procedures are now in place to perform the testing of the about 70000 electrical interconnections of the superconducting magnets in the LHC.

ACKNOWLEDGEMENTS

The authors thank M. Zerlauth for his contribution in matters regarding the LHC reference database and the electrical circuit layouts.

REFERENCES

[1] N. Siegel, "Electrical Quality Assurance During Installation of Cryo-assemblies in the LHC Tunnel", LHC Days, 19-21 March 2001.
[2] K. H. Mess, "Test of the Interconnections of the Line N", LHC Days, 19-21 March 2001.
[3] D. Bozzini, "The Standard Instrumentation Feedthrough System for the LHC Cryo-magnets", MT17 Conference, 19-21 March 2001.
[4] M. Zerlauth et al., "The Electrical Circuit Description for the LHC", EPAC'02, Paris, p. 2058.
[5] J. Ph. Tock et al., "Electro-mechanical Aspects of the Interconnection of the LHC Superconducting Corrector Magnets", these proceedings.
[6] E. Manola Poggioli, "The Manufacturing and Test Folder: MTF", EPAC'02, Paris.