

AUTOMATIC MEASUREMENT SYSTEM FOR ELECTRICAL VERIFICATION OF THE LHC SUPERCONDUCTING CIRCUITS

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Abstract

In the LHC machine, superconducting magnet circuits are used on a very large scale. The circuits, more than 1600, are all equipped with a complex set of instrumentation required for safe operation and diagnostics. The length of many circuits exceed 3 km. Due to risks of accidental damages during transport and assembly or misconnection of the circuits' auxiliary components, it is necessary to perform an Electrical Quality Assurance (ELQA) campaign after every major intervention on a circuit and also after each thermal cycle of the machine. In order to be able to perform reliable tests on a circuit within a short time frame, a highly extensible automated mobile test system was designed and built. Four of these instruments were successfully used during the Hardware Commissioning phases of the LHC. This paper describes the hardware solutions used in the test system.

INTRODUCTION

A typical LHC superconducting circuit consists of superconducting coils, superconducting bus bars, current leads (providing transition between super conducting and normal conducting part of circuit), warm cables leading to the power converter and voltage pickups placed mostly on the cold part of the circuit – used by quench protection systems and for diagnostics. With this setup, one can detect a number of possible faults of the circuit: polarity error on the current supply path; misconnection of the voltage sensing cables; open circuit; broken voltage pickup connection; abnormal circuit resistance, inductance, capacitance; abnormal voltage pickup resistance; short circuit, high leakage current or electrical insulation breakdown at voltages below operation requirements. Main superconducting magnets of the LHC are equipped with quench heaters, which can have following faults: open circuit; abnormal resistance of circuit; short circuit, high leakage current or insulation breakdowns. This paper describes the mobile test system which is able to detect all mentioned faults and perform other electrical measurements.

CONSTRUCTION

The mechanical construction of the measurement system based on an AIV (Arc Interconnection Verification) [1] modified trolleys with 19 inch racks added. Every trolley is additionally equipped with boxes used for storage of the measurement cables and tools. As a general purpose measurement instrument, a Keithley 2750E digital multimeter/switching system was chosen.

The modules are installed on movable trolley. The system is controlled by a set of dedicated LabVIEW® applications running on laptop computers. The communication between computers and instruments is done via GPIB bus, except for Automatic System for the DC High Voltage Qualification where USB and RS232 buses are used. The measurement system block diagram is shown on Fig. 1.

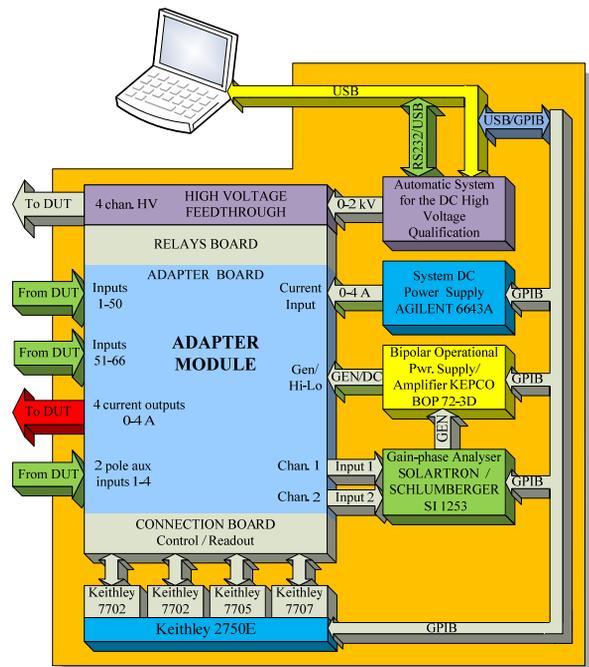


Fig. 1: Measurement system block diagram

Adapter Module

The Adapter Module is used to configure connections between Device Under Test (DUT) and the remaining instruments (also between the measurement devices itself) of the measurement system. The module consists of three printed board circuits: the Connection Board, Adapter Board and Relays Board. All three components of Adapter Module are installed in 3U 19-inch crate. On a front plate of the module a set of connectors is available to connect all kinds of superconducting circuits to be found in the LHC via proper adaptor cables.

Adapter Board

On the Adapter Board one can find a power supply for the whole Adapter Module, 16 relays controlled by the Keithley 7707 card and two 1 Ω reference resistors. The main task of the adapter board is routing of the current from the DC or AC power supply through the reference resistors to one of four system outputs. By means of

relays, it is possible to reconfigure the outputs to the insulation measurement mode. Such configuration is used during transfer function measurement of the insulation. The resistors are used for a precise current measurement. They also set the value of current when working with power source in constant voltage mode. In order to assure stable resistance, resistors are thermally stabilised by the Atmel ATmega8 based temperature controller.

Connection Board

The Connection Board PCB (Printed Circuit Board) was originally designed for the AIV system [1]. The PCBs after a small modification are used successfully in our measurement system. The board being connected to the Keithley cards 2x7702, 7705 and 7707 can bring any two of 80 input terminals to the single input of measurement device. Some of the input terminals are connected to the pickup points on the Adapter Board (e.g. extremities of reference resistors), the rest is available on the front panel of adapter module for connection to the tested circuit or other DUT.

Relays Board

Relays board is equipped with set of relays used for special purposes, such as discharging of magnet coil when measuring superconducting magnets or auto calibration of the system. This board carries also a microcontroller used for temperature control of the reference resistors.

Insulation Tester

The measurement system is equipped with Automatic System for the DC High Voltage Qualification described in [2]. The high voltage system located in 6U crate can connect up to 80 circuits. The HV system is used for qualification of circuits electrical insulation to ground and to other circuits. It is capable of energizing circuit up to 2 kV and can measure leakage current in a range of 1 nA to 2 mA.

MEASUREMENT TYPES

The system is used to perform following test types:

- Instrumentation Resistance Check (IRC) – Measurement of the voltage pickup resistance. Typically two wire method with calibrated connection cable is used.
- Ohmic Resistance Check (ORC) – Resistance measurement of tested circuit at the current order of magnitude of single amperes.
- Instrumentation Continuity Check (ICC) – System applies DC current through the circuit and measures sequence of the voltage drops between voltage pickups along the circuit. This test helps in identification of misconnected voltage taps.
- Transfer Function Measurement (TFM) – Tested circuit is powered using AC source. System records circuit impedance and phase between current and voltage over the circuit at different frequencies (1 Hz to 10 kHz). Results of this test are used to detect

faults like internal turn-to-turn short circuits in superconducting coils.

- Transfer Function Measurement of insulation (TFM vs. GND) – Similar to the TFM. This test provides early detection of short circuits to ground (and other insulation degradations) with an approximate information on the location of the short circuit in case of the long circuits.
- High Voltage Qualification (HVQ) – System measures insulation leakage current at the voltage levels from 180 to 1900 V depending on the circuit type and cryogenic conditions. In case of quench heater insulation measurement name QHVQ is used.
- Quench Heater Resistance measurement (QHR) – System checks resistance of the quench heaters and compares it to the reference value.

APPLICATIONS

The measurements performed on LHC circuits during qualification stages described in [3] are grouped into three applications: Test Procedure 4 (TP4), Dipole Orbit Corrector (DOC) and Magnet Instrumentation Check (MIC). Each type of measurements is performed at room temperature and at cryogenic conditions.

TP4 Application

Applications from the TP4 family are used to perform tests on superconducting circuits powered via DFBs (Distribution Feed Boxes). Name TP4 has been used in order to emphasise the fact that this kind of tests is continuation of 3 prior test procedures. Block diagram of TP4 setup is presented on Figure 2.

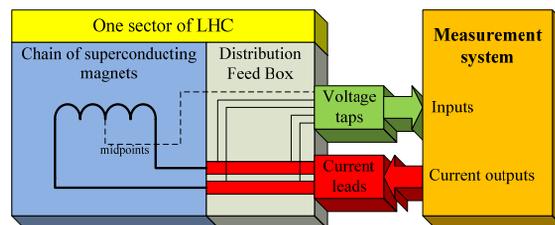


Figure 2: TP4 application block diagram

Current outputs of the system are connected to the current leads of the circuit, and voltage inputs of the system are connected to all the available voltage taps on the circuit (up to 8 per current lead and in some cases middle points of the coils). With this configuration the system can perform a set of low voltage tests. Then for the insulation test, circuit is connected manually to the insulation tester embedded in the measurement system. For security reasons, this switching process requires a manual intervention of the operator.

DOC Application

DOC applications are used to test individually powered superconducting orbit corrector dipoles called DOC. Each Short Straight Section of LHC contains two such circuits. Figure 3 presents DOC application block diagram.

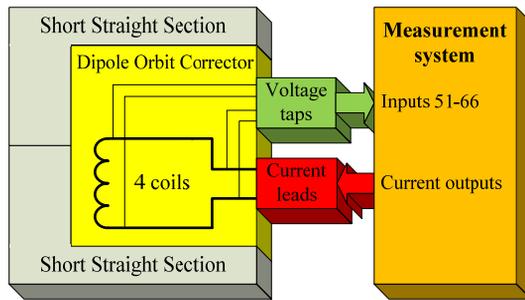


Figure 3. DOC application block diagram

By default four DOC circuits are connected at once to the equipment and tested in a row with each application. In this case there are also separate low voltage and high voltage connectors, so that the operator is fully aware when switching over to HV insulation tests.

MIC Application

Magnet Instrumentation Check concerns all the main dipole and quadrupole magnets in the LHC. System checks the integrity of local voltage taps, quench heaters resistance and quench heater electrical insulation. Figure 4 shows block diagram of this family of tests.

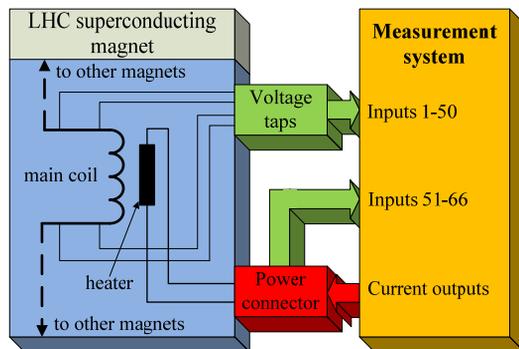


Figure 4. MIC application block diagram

When performing heater insulation check, operator must use separate set of connectors available in the measurement system.

CONCLUSIONS

The described measurement system has proven its reliability during tests performed on all superconducting circuits in the LHC. Each of over 1600 circuits was qualified 5 times in average at different stages of the LHC start-up. Table 1 shows approximated number of most frequent problems found so far in the LHC with the help of our measurement system.

Great majority of those faults if left undetected could have caused serious damages to the LHC machine.

Currently the system is being upgraded and is planned to be used during future shutdowns of the LHC.

Table 1: Number of recognised LHC faults

Type of fault	Count
Dead voltage tap	30
Increased resistance of voltage tap	35
Misconnected voltage taps	15
Insulation problems	Over 100
Wrong resistance of current leads/bus bars	90
Coil found resistive or open	17
Reversed polarity of the circuit	25
Wrong resistance or open quench heater	8

FURTHER WORK

Currently, a new version of the measurement system is under development. In addition to the existing test system some new features listed below will be implemented:

- 4 wire measurements between any of 80 input terminals
- Improved stability and raised value of the test current
- Extended range of frequencies for AC tests
- Improved signal shielding and noise immunity
- Complete independency between measuring devices

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