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FIRST EXPERIENCE WITH THE LHC CRYOGENIC INSTRUMENTATION

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Abstract

The LHC under commissioning at CERN will be the world's largest superconducting accelerator and therefore makes extensive use of cryogenic instruments. These instruments are installed in the tunnel and therefore have to withstand the LHC environment that imposes radiation-tolerant design and construction. Most of the instruments require individual calibration; some of them exhibit several variants as concerns measuring span; all relevant data are therefore stored in an Oracle® database. Those data are used for the various quality assurance procedures defined for installation and commissioning, as well as for generating tables used by the control system to configure automatically the input/output channels. This paper describes the commissioning of the sensors and the corresponding electronics, the first measurement results during the cool-down of one machine sector; it discusses the different encountered problems and their corresponding solutions.

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ABSTRACT

The LHC under commissioning at CERN will be the world's largest superconducting accelerator and therefore makes extensive use of cryogenic instruments. These instruments are installed in the tunnel and therefore have to withstand the LHC environment that imposes radiation-tolerant design and construction. Most of the instruments require individual calibration; some of them exhibit several variants as concerns measuring span; all relevant data are therefore stored in an Oracle® database. Those data are used for the various quality assurance procedures defined for installation and commissioning, as well as for generating tables used by the control system to configure automatically the input/output channels. This paper describes the commissioning of the sensors and the corresponding electronics, the first measurement results during the cool-down of one machine sector; it discusses the different encountered problems and their corresponding solutions.

KEYWORDS: cryogenic instrumentation, commissioning, LHC.

INTRODUCTION

From the cryogenic instrumentation and controls point of view, a full LHC sector has been commissioned during the first half of 2007. It has been successfully cooled to nominal conditions and the overall performance of the instrumentation and control system

is excellent. Presently the warm commissioning of the instrumentation is performed in up to three sectors in parallel.

INSTRUMENTATION REVIEW & CONSTRAINTS

Tunnel Hardware and LHC Environmental Conditions

FIGURE 1 shows the LHC standard cell instrumentation. Instrumentation were installed either during the fabrication of LHC elements like superconducting magnet and cryogenic distribution line (QRL), or during the field assembly in the tunnel, like Line N instrumentation.

Some instrumentation channels are critical for the operation and in this case the instruments are either redundant or exchangeable without breaking the insulation vacuum. Redundancy is typically applied for thermometers that cannot be exchanged unless a major mechanical operation is undertaken. Exchangeable instruments are typically the liquid helium level gauges installed in stand alone magnets and electrical distribution feedboxes (DFB).

The ionizing radiation present in the LHC tunnel imposes qualification campaigns. Some instruments by design are intrinsically radiation hard; this is applicable for electrical resistors and level gauges that use the same materials as the superconducting magnets. The cryogenic thermometers have been qualified in nominal conditions [1] to radiation doses up to $4 \cdot 10^{14}$ n/cm² that represent the expected radiation in the dispersion suppression zones but can underestimate significantly the radiation level close to the interaction points. Irradiation campaigns have been performed for pressure sensors [2] and for all tunnel electronics [3]. The electronics relies on both Commercial Of The Shelf (COTS) and radiation hard components like the front end Application-Specific Integrated Circuit (ASIC) and the CERN voltage regulators [4].

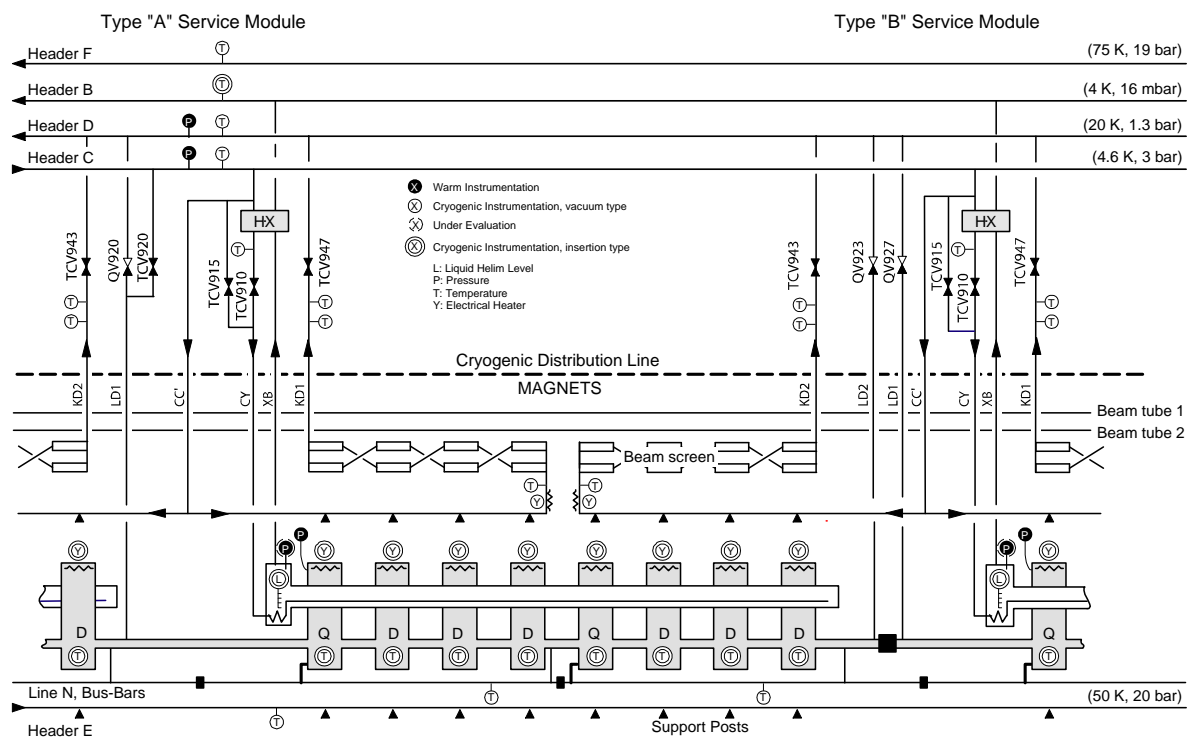


FIGURE 1. LHC standard cell instrumentation.

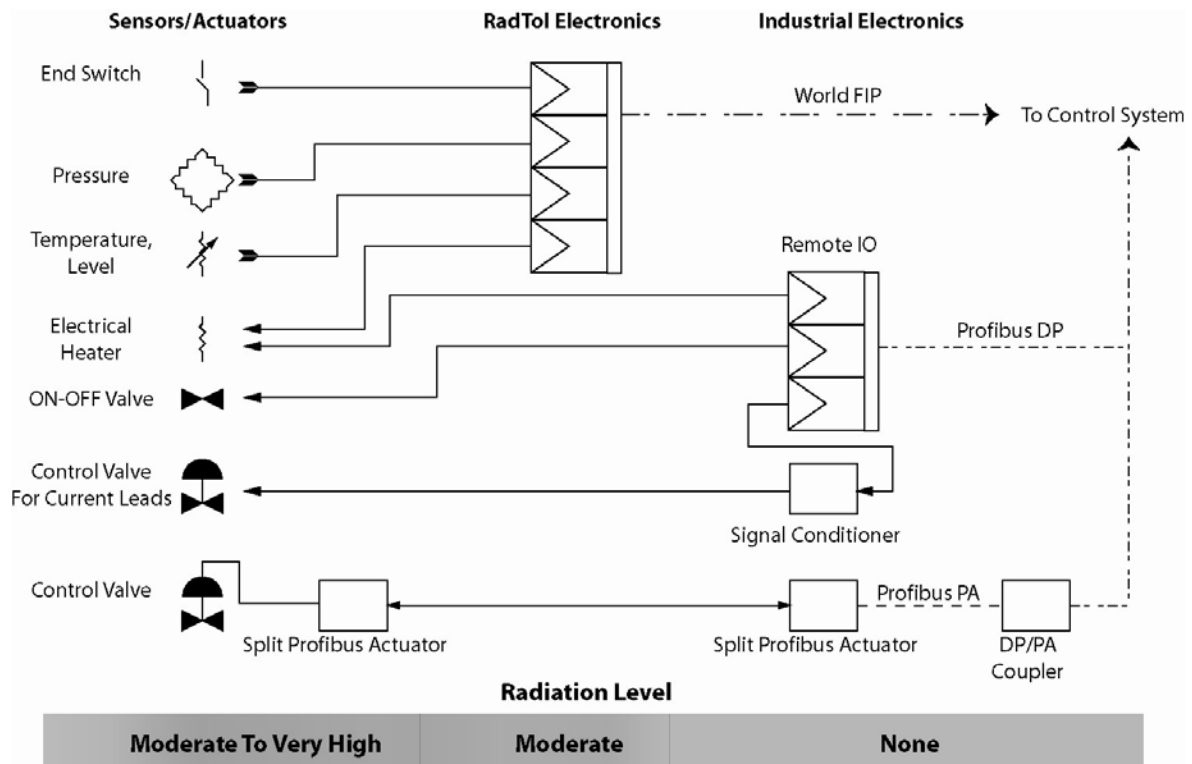


FIGURE 2. Exposition to ionizing radiation.

Expected radiation maps have been simulated for the operation of the LHC. This dictated that electronics could be placed only in the LHC arcs and dispersion suppressor zones in the most optimal location which is under the main dipoles. The main dipoles iron yoke acts as radiation shield for the neutrons that are the major component of the LHC radiation. For the long straight regions all the electronic components are installed in radiation protected areas. FIGURE 2 shows the exposure to ionizing radiation of the instrumentation.

Instrumentation Sensors

Two types of resistance temperature sensors are specified to cover specified range in the cryogenic system. According to selection and qualification criteria [5], Cernox™ thin-film resistance cryogenic temperature sensors manufactured by LakeShore were selected, including an individual calibration from 1.6 to 300 K [5]. For the second type, selection of a robust and industrial Platinum Resistance Thermometer (PRT) was agreed. It offers the main advantages of a high repeatability and is interchangeable above 70 K with a single normalized calibration curve.

Pressure sensors in the ranges 0-4 and 0-20 bar are based in passive strain gauges and manufactured by Baumer. A 100 mbar absolute low pressure sensor, and ± 350 mbar differential low pressure sensor are manufactured by Shaewitz.

Liquid helium level gauges manufactured by Cryogenic Limited were selected. The measurement of depth is based in the variation of resistance due to the loss of the superconducting state for the fraction of the sensing wire located in the gas. Various active lengths (150, 400, 500 and 600 mm) are required.

The electrical heaters are based on either interchangeable cartridge or foils glued on the outer vessels working under vacuum conditions or standard wire wound resistors.

Electronic and Acquisition System

The electronic system is mainly composed of a signal conditioning card and a communication card. All the sensors and actuators measurements are considered as resistor type translated by Programmable Logic Controllers (PLC) into the corresponding magnitude through individual or standard calibration curves (see FIGURE 3). Therefore, the conditioning cards are closely related to transducers and split into the following blocks: the ASIC, the Analog to Digital Converter (ADC) and the Field Programmable Gate Array (FPGA). The ASIC, designed by CERN, holds the different current sources and a differential amplifier to transform the signal from sensor into the appropriate levels to the 16-bit ADC. The FPGA is in charge to control both the ASIC and the ADC, to filter data and multiplex the two different channels per card and to provide results to communication card. Two extra blocks are added for specific cards for helium level gauge and electrical heater: a power amplifier used to warm up the sensor and feed it for measurement combined with a Digital to Analog Converter (DAC) to control the output power amplifier. The communication system is composed of a mother and daughter board - two microchip mezzanine cards implementing the worldFip protocol from Alstom - to transfer conditioning data to PLCs and FPGAs programmed for emulating the communication processor.

The cryogenic operation and data storage are performed on an Operating WorkStation (OWS) linked to PLCs through Ethernet. It runs a Supervisory Control And Data Acquisition (SCADA), which was an in-house development based on industrial software PVSS II from Siemens. In addition, a Cryogenic Instrumentation Expert Tool (CIET) was developed to have a remote access to electronic crates for diagnostic, configuration and reset operations.

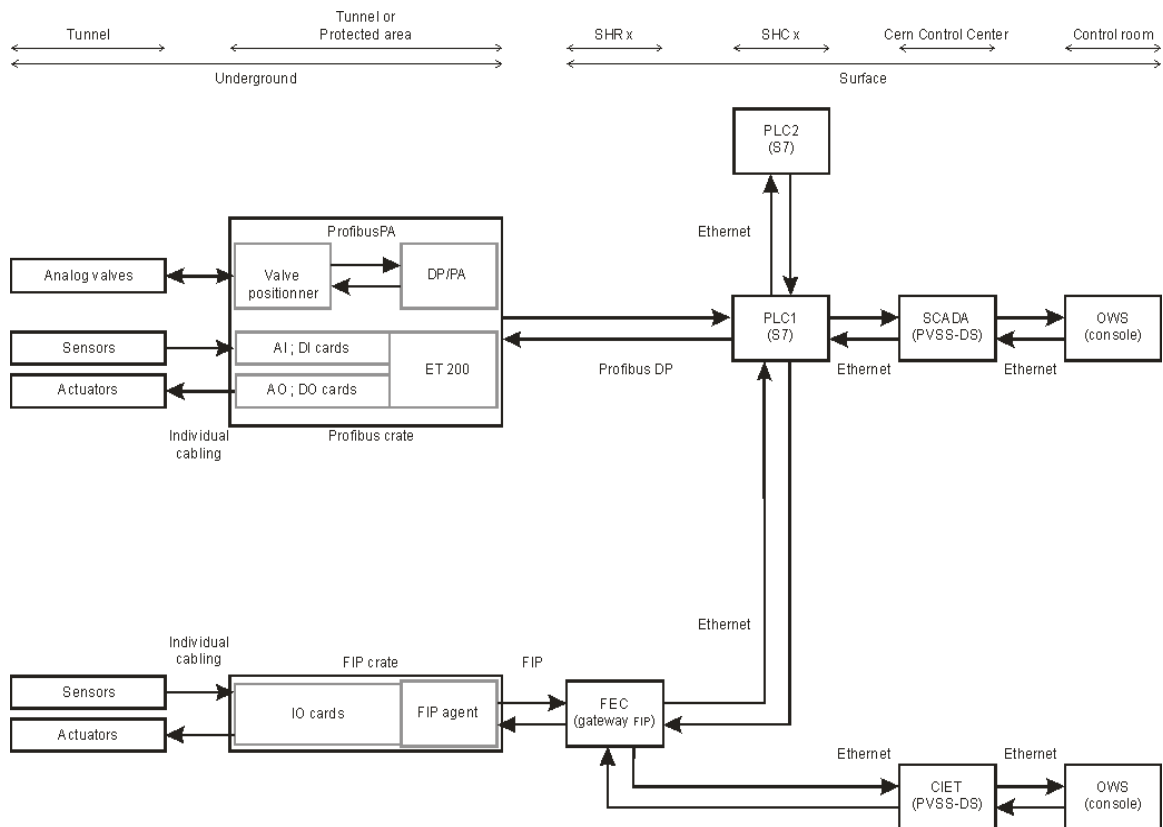


FIGURE 3. Overview of cryogenic instrumentation and control architecture.

QUALITY ASSURANCE TOOLS & PROCEDURES

The LHC machine is classified as a “Installation Nucléaire de Base” (INB), therefore a complete list of document types, naming convention, tools and procedures were defined to guarantee performance and traceability of all equipments [6].

Procedures and Documentations

The instrumentation reception procedure consists of checking the presence of the instrument according to the process and instrumentation diagram and validating the correspondence between serial number and LHC location, the proper registration and traceability in a safe database and the availability on SCADA. Specific procedures are applied for PRT installed on High Temperature Superconducting (HTS) current leads requiring high voltage compliance in a range from 600 V up to 1.9 kV; the validation comprises the sensors, electrical cables, connectors and regrouping panels.

Documentation was crucial to face the huge and multiple users involved in the manufacturing of the LHC machine. The capture and storage of assembly, test and installation production data was carried out by an individual traveler, provided with associated certificate of conformity. Any deviation from specification, installation or conformance results is traced back with a non conformity report defining disposition and corrective action and ensuring the traceability of the event.

Reliability and Robustness of Data

An Electronic Data Management System (EDMS) application permits to store, organize and control all engineering data on a safe Oracle® database. Furthermore, based on the same EDMS common layer a Manufacturing and Test Folder (MTF) application allows accessing or creating documentations and pre-defined procedures of individual equipment. As a result, the procedures for the different LHC machine equipments were mostly identical and standardized.

For the operation phase, CERN designed and developed the LHC Functional Layout Database, which stores all data pertaining to the layout of the LHC machine and its components, as a large unified tool based on an Oracle® database and web interface. It is mainly based on a conceptual object identified as a slot defining the functional position of each piece of equipment installed in the tunnel. Then, equipment slots are linked together to describe the complete instrumentation channel by a conceptual parent-child relationship between assemblies and components or by a physical cabling between two unrelated slots. The last type of link has then its own properties such as pin out mappings, cable numbers and cable types.

Field Validation Tools

Classical test boxes and portable instruments were not reliable enough to face the extensive quantity of equipments. Therefore, mobile test benches were designed and manufactured in-house for checking the cryogenic instrumentation on LHC machine, taking into account environmental constraints such as size, displacement, safety of equipment and user, and validation criteria. These tools are able to operate directly on the machine side or at the output of the electronic crate. The first operation confirms that the instruments are installed and operational. Then, the second operation in front of electronic crate includes 3 main set-ups:

- checking the consistency of the data with respect to the LHC layout database,
- simulation of the instrument using a programmable resistor to set a value and compare it with the reading output to validate the data acquisition system,
- final global testing including instruments, electronic card and communication to validate the complete instrumentation chain.

From a Visual Basic Application (VBA), an extracting tool allows field inspectors to check installation and integrity of electrical connection on machine side and electronic crates. All reports were stored with EDMS application and used to follow the corrective actions when applicable like for instance damaged connectors or missing cables.

QUANTITATIVE AND QUALITATIF RESULTS

Instrumentation Availability

The mobile test benches were not fully available for reception, and an alternative solution was to perform field measurements to validate instrumentation installed on the machine side. This first part of the warm commissioning was done in 5 weeks. The reception of instruments before the cool-down of the first sector 7-8 confirms a low rate of degraded and damaged equipments. Heaters, helium level gauges and pressure sensors were all operational. Concerning the cryogenic thermometers the non operational quantity (detailed in TABLE 1) corresponds mainly to the non interchangeable equipments damaged during machine fabrication.

The field measurements were crosschecked with the SCADA. In total, 729 channels are operational over a total of 787. Even if the failure rate is 7.3 % and exceeds the status deduced from field measurements, problems are clearly identified from electronics, cabling or possible wrong identification of equipments. A repair campaign is therefore foreseen after the warm-up of sector 7-8 by the end of July 2007.

Cryogenic Instrumentation Performance

FIGURE 4 shows the temperature spread for cryogenic thermometers installed in the superconducting magnets immersed in a pressured bath of superfluid helium at 0.13 MPa, The reproducibility is well within the LHC specifications. Furthermore, the profile temperature data confirm the possibilities to monitor the entire LHC standard cell even with two consecutive unavailable sensors.

TABLE 1. Thermometers status from field measurements.

	Installed	Operational		Degraded		Damaged	
Superconducting Magnets	204	193	95 %	3	1.5	8	3.9
Cryogenic Distribution Line	254	253	99.6 %	1	0.4 %	0	0 %
Line N and C' thermometers	108	108	100 %	0	0 %	0	0 %
DFB without HTS leads PT-100	59	59	100 %	0	0 %	0	0 %
Inner Triplet Equipments	37	37	100 %	0	0 %	0	0 %
Total	662	650	98.2 %	4	0.6 %	8	1.2 %

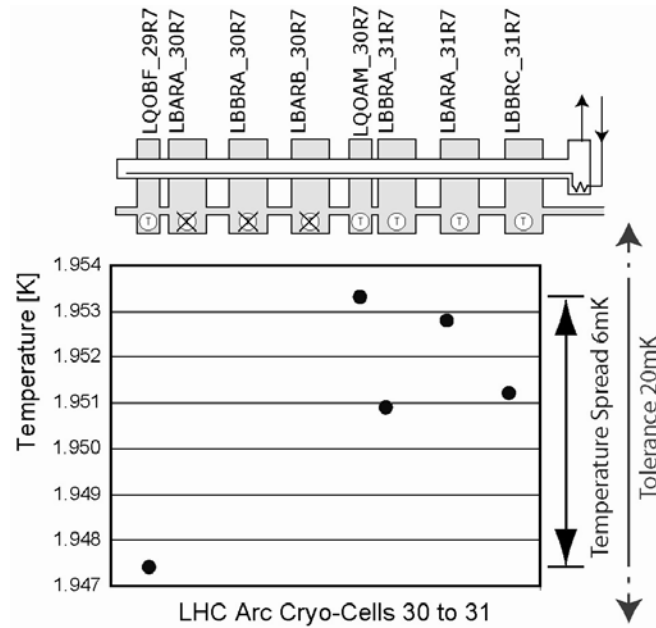


FIGURE 4. Profile temperature for a single LHC standard magnet cell in arc tunnel.

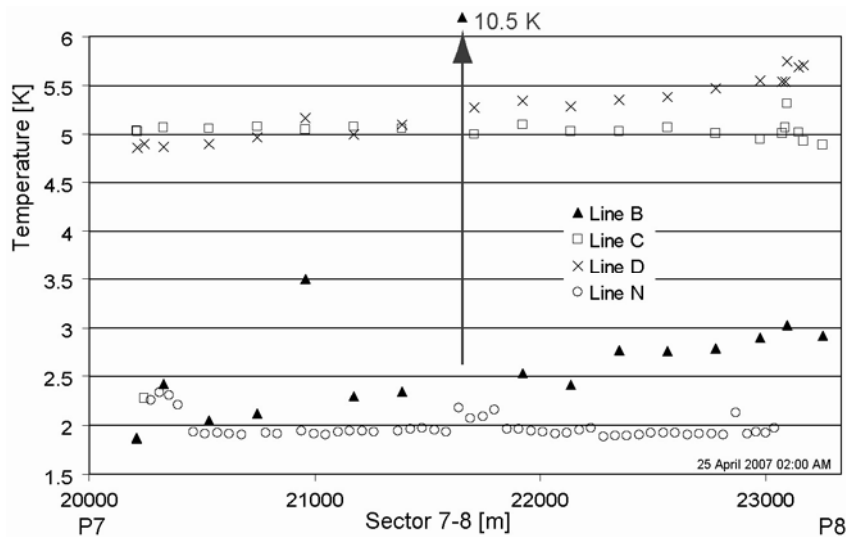


FIGURE 5. Profile temperature for cryogenic distribution line.

The temperature profiles measured along the tunnel permit to qualitatively assess the correct operation of the temperature channels. The observed performance in FIGURE 5 is perfectly appropriate with the operational requirements [7]. However, conclusions concerning the metrological performance are difficult to establish.

EXPERIENCE RETURN

Concerning the low-pressure range sensor, it was impossible to qualify an appropriate sensor compatible with the designed electronics. The selection and qualification of such sensors are delayed to a future LHC consolidation phase.

During installation phase, it was detected that the wire insulation material of the level gauges was not compatible with the radiation environment. Therefore all gauges were

disassembled to exchange the sensing wires. These repairs have degraded the geometrical tolerance for the active measuring length of the gauges and have consequently required in-situ verifications and recalibrations to guarantee the control of the level of the HTS current leads within an absolute value of +/- 10 mm.

The commissioning procedures can detect basic design problems for instance cables which cannot withstand the design operating voltage. This problem imposed to modify the cable specifications and to launch a new cable installation campaign for the 13kA HTS current lead thermometer read-outs. Field measurements compared to the corresponding individual traveler were confirmed as a mandatory test set-up to trace quality assurance procedure and data registration. It reduces significantly the time to detect and confirms defective or swapped channels. In addition, a link between databases is now available to access the corresponding MTF data for an object in a slot directly from the layout database and vice-versa.

CONCLUSIONS

The commissioning carried-out for the first time in the sector 7-8 was a practical field experience to fine tune our installations tools and procedures. It permits to improve the operator skills in the perspective to test several sectors in parallel as required by the LHC master schedule. As a preliminary result, the next sector (sector 4-5) was commissioned before the start of the cool-down and the field data confirm a better coherence between field measurements and SCADA. With the present experience we feel confident that the strategies and instruments selected are adequate to comply with the LHC schedule and with its operation.

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