Mobile Test Bench for the LHC Cryogenic Instrumentation Crate Commissioning

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Abstract

The Large Hadron Collider (LHC) at CERN is a two-ring superconducting accelerator and proton-proton collider of 27 km circumference, which is in operational phase. The dipoles operate at 8.3 T, cooled by superfluid helium at 1.9 K. The operation and monitoring of the LHC require a massive amount of cryogenic instrumentation. This paper focuses on the commissioning of the cryogenic instrumentation.

I. INTRODUCTION

The Large Hadron Collider (LHC), the circular proton-proton accelerator will reach beam energy of 14 TeV (center of mass) and luminosity of 10^{34} $cm^{-2}s^{-1}$ [1]. The LHC ring consists of 8 sectors (Figure 1), each divided in: regular arc (ARC, ~2.5 km), 2 dispersion suppressors (DS, ~0.5 km) and 2 long straight sections (LSS, ~0.5 km). The operation and monitoring of the LHC require a massive amount of cryogenic instrumentation channels - most of them operating in radioactive environment - with a robust and reliable design. The cryogenic control system has to manage more than 16 000 cryogenic sensors and actuators.

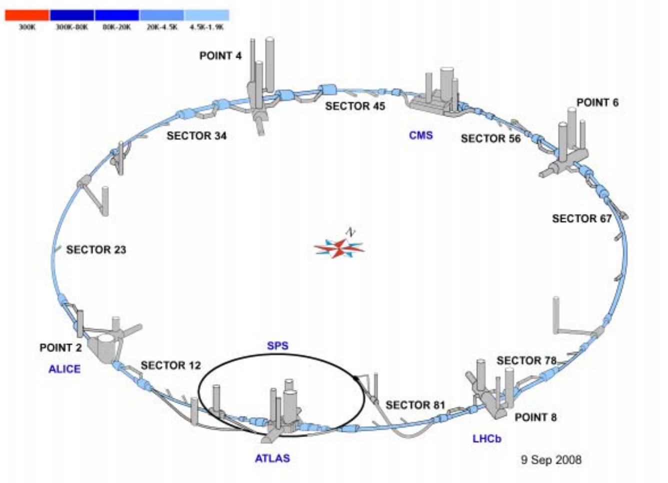

Figure 1: The LHC sectors and interaction points. P1: ATLAS detector, P2: ALICE detector, P3: Collimation system for off-momentum particles, P4: Radio Frequency superconducting acceleration cavities, P5: CMS detector, P6: Beam abort systems for the beams extraction, P7: Collimation system for the beam halo, P8: LHCb detector.

II. INSTRUMENTATION ELECTRONICS

More than 800 instrumentation crates (Figure 2) are installed, connected and tested underground. They house electronic cards for the temperature (TT), pressure (PT) and liquid helium level (LT) measurements, supply electrical power to the cryogenic heaters (EH) and read the digital valve status [2].

Figure 2: Instrumentation crates under the dipoles (left) and in the radiation protected areas (right).

These crates communicate through a FieldBus, based on the WorldFip protocol [3].

The Instrumentation readout is performed through 2 field-busses:

- Profibus for valve actuation. Located at 4 underground protected areas and connected through optic fiber to two PLC (ARC/LSS-surface).
- WorldFIP for TT, PT, LT, valve position reading and heaters. Up to 80 crates (radiation tolerant) distributed in the tunnel, other 20 crates/sector in protected areas.

There are also two Supervisions Systems in parallel:

- SCADA-CRYO for the LHC cryogenic operation (synoptic channels for navigation, monitoring and control of all instruments, alarms and interlocks handling, real-time and historical trends, data/event logging and archiving).
- CIET (Cryogenic Instrumentation Expert Control) for the access to the data of the WorldFIP instrumentation channels (remotely

monitor, configure, parameterize and reset read-out channels).

The commissioning of the Cryogenic Instrumentation [4] (electronics, cabling, sensors, actuators), after their installation in the LHC tunnel is done with a Mobile Test Bench (MTB).

Four Test Benches have been built at CERN to ensure the correct functionality of all electronics (three of them are used for tests and the fourth for debugging-development and for the pressure sensors calibration).

III. MOBILE TEST BENCH

The MTB (Figure 3) is based on a PXI platform, running LabVIEW™ application (Figure 4). The PXI rack houses:

- An embedded controller by National Instruments, running Windows XP.
- Two FIP communication cards for the top and bottom level of the crates with different FIP addresses.
- A 276×8 matrix module by Pickering for the switching of connections between the MTB instrumentation and the cards/cables under test.
- One programmable resistor module by Pickering for the simulation of the various sensors during the card tests.
- Various other cards (power supply card, multimeter card).

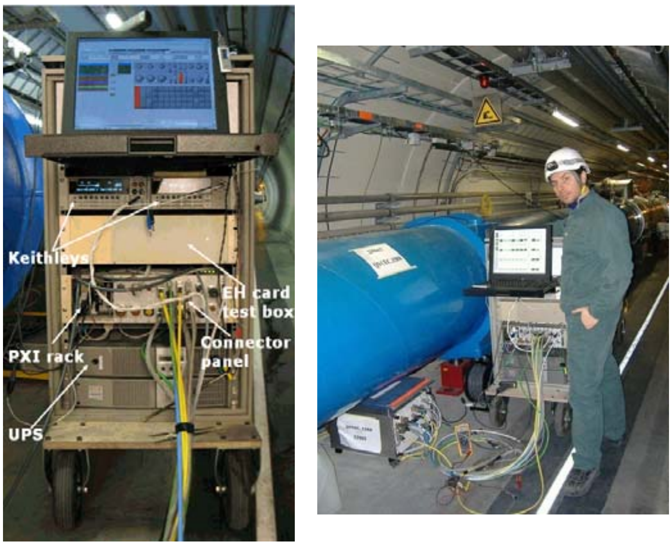

Figure 3: Mobile Test Bench.

Other important components of the MTB are:

- One Keithley 2400 SourceMeter for resistance measurements in 2-wire mode and current sourcing for the 4-wire measurements.
- One Keithley 2182 Nanovoltmeter for accurate voltage sensing for the 4-wire measurements.
- A connector panel, which provides the physical interface between the MTB instrumentation and the cards/cables under test.
- One heater card test box, which houses power relays that are used to route power from the heater card to the load during the heater card test (PXI matrix can't handle the current drawn by the load).
- One UPS, which supplies all MTB electronics with AC mains power (removal of the MTB from one crate to another, without to shut it down).

The MTB project uses Perforce, a Software Configuration Management (SCM) tool, which provides a centrally managed storage area for all files of a project, keeps detailed track of the history of each managed file (versions, changes, bug-fixes, comments, etc.) and allows collaboration amongst users.

More specifically Perforce is used to manage the LabVIEW software distribution from the developer team to the operator team, individual crate configuration files and also the results for all cryogenic instrumentation crates. All crate data stored in layout database. XML data files (CIDs, FIP addresses, type of cards, active channels, cable numbers, type of sensors etc) are used to overcome constraints such as size and complexity of layout database, network presence and speed at the tunnel.

The results are stored locally in the corresponding folder of the crate and after the completion of tests are submitted to the Perforce server and MTF - a database that stores the data related to the management of the LHC equipment. Information about electronics and instrumentation is stored in Layout Database.

The following tests are performed with the MTB:

- Consistency test: verification of matching of the crate configuration with the CERN Layout DataBase
- Card test: check electronic cards functionality
- Instrument test: check instruments presence and their functionality
- Pin-to-Pin test: validation check for cables and connectors (short circuits, low insulation resistance)
- FIP test: functionality verification of the full readout chain (sensor+electronics).

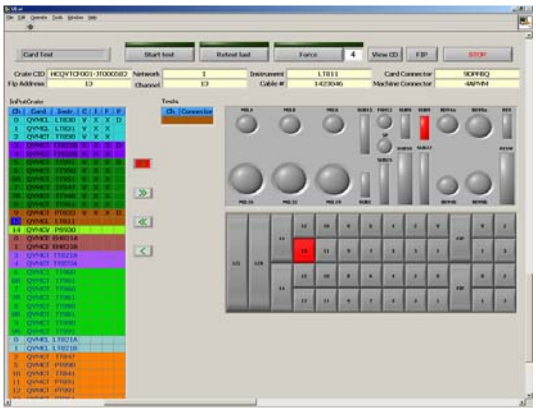

Figure 4: Mobile Test Bench LabVIEW screenshot.

A. *Monitoring*

Monitoring (Figure 5) is not actually a test, but a useful tool that shows all the measurements the crate performs (crate not powered, missing or not connected cable, instrument improperly installed and electronic card not operational). It provides an overview of all data that the crate feeds to the FIP network (sensor measurements, noise levels, card state etc).

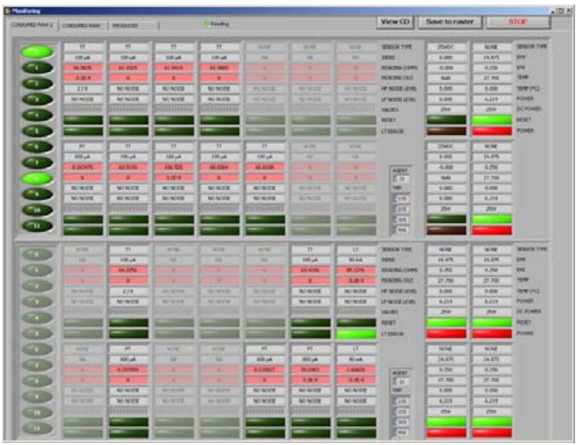

Figure 5: Monitoring Test.

B. *Consistency Test*

Purpose of the test is the comparison of the crate configuration with the CERN Layout DataBase (Figure 6).

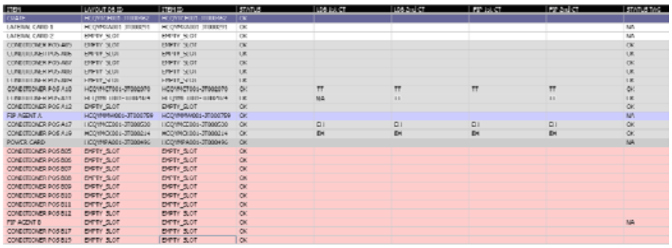

Figure 6: Consistency test.

C. *Card Test*

Purpose the test (Figure 7) is the validation of the correct functionality and accuracy of each electronic card. This is the only test for which the criteria pass/fail (reference values, tolerances, etc) are hard-coded in the MTB software, implemented for every card type.

Figure 7: Card test.

D. *Instrument Test*

Purpose of the test is verification that each instrument (sensor/actuator) is physically present at the machine, correctly wired and properly connected and it has the expected resistance value, given the instrument type and the machine conditions.

The test (for TT, PT, LT) is based on the 4-wire method (Figure 8), which uses two pairs of wires, one pair to apply excitation current and another pair to measure the voltage drop across the sensor.

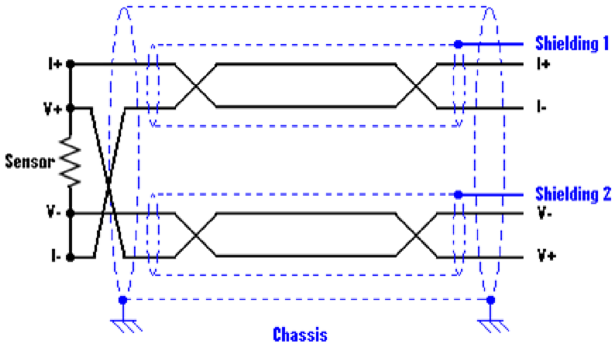

Figure 8: 4-wire method for the Instrument test.

E. *Pin to Pin Test*

Purpose of the test is the detection of the electrically measurable errors in cable/instrument (short circuits and low insulation resistance) with measurement of the resistance between all pin combinations of a cable connector and the resistance between each pin of the connector and ground (Figure 9) in 2-wire mode.

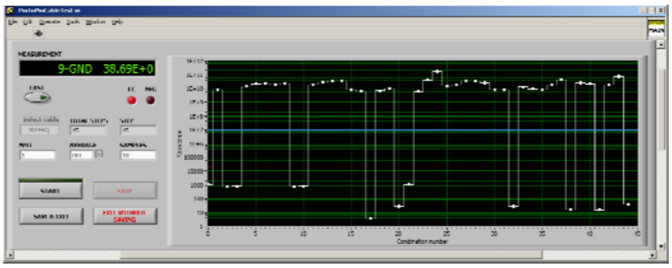

Figure 9: Pin to Pin test.

F. *FIP Test*

Purpose of the test, which is the last MTB test, is a final cross check, as it requires all the cables to be connected back to the crate. The FIP functionality is already checked during the card test. During the test the 4-wire resistance value of the sensor is returned and comparison with the 4-wire measurement of the instrument test takes place.

G. *Troubleshooting Tools*

The most common problems are related to electronic cards, instruments, cables, bad contacts, short circuits, open circuits, wrong grounding, database views refresh state, missing info in the database, FIP communication or components of the MTB itself.

The troubleshooting tools are the stand-alone loads (connectors with discrete resistors internally connected), digital multimeter matrix relay test and cabling test.

Purpose of the matrix relay test is to check the MTB matrix for stuck open relays or relays with worn out contact. It measures the resistance of all possible paths (relay combinations) and reports all paths with resistance value higher than a predefined limit.

Purpose of the cabling test is to identify possible short circuits in the MTB wiring. The test includes the matrix, the connector panel and the MTB cables.

H. Planning

Three mobile test benches have been used, working in parallel, having two shifts per day (morning/evening), when necessary.

The test duration varied between 2 and 10 hours/crate, depending on the crate equipment and complexity.

The rate achieved is ~2-3 crates/MTB/shift in average for the ARC (tunnel) and ~1 crate/MTB/shift for the LSS (protected areas), while the commissioning duration was 2-3 weeks per sector (tunnel) and 1 week for protected areas depending on problems. The increased experience accelerated the procedure to this level. The second or third pass after the repairs for cross check has not been taken into account.

IV. CONCLUSIONS

The MTB is a valuable tool for finding most problems with cards, cables, sensors and connectors (i.e. wrong or not connected cables to the field instrument, wrong grounding/shielding in the cables or connectors, bad contacts, short circuits, open circuits, blown fuses, damaged cables or connectors, missing connections, missing info in the database, and mismatches with specifications and database).

It is a relatively complicated tool with long debugging period for exhaustive checks. Increased responsibility of the operator for results interpretation/evaluation and reporting was necessary for the commissioning of approximately 800 electronic crates and more than 12 000 cryogenic sensors and actuators.

The perational performance (within specifications) has exceeded 98% for thermometers and ~100% for other instruments.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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