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INSTRUMENTATION, FIELD NETWORK AND PROCESS AUTOMATION FOR THE LHC CRYOGENIC LINE TESTS

T. Bager, Ch. Balle, G. Bertrand*, J. Casas-Cubillos, P. Gomes, Cl. Parente, G. Riddone, A. Suraci

Abstract

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Considering the diversity, amount and geographical distribution of the instru-mentation involved, this is a representative approach to the cryogenic control system for CERN's next accelerator.

LHC Division
* SGTE Travaux Electriques, Technoparc Gessien, rue Gustav Eiffel, 01630 Saint-Genis-Pouilly, France

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Troels Bager, Christophe Balle, Guy Bertrand*, Juan Casas, Paulo Gomes, Claudia Parente, Germana Riddone, Antonio Suraci

LHC Division, CERN, 1211 Geneva 23, Switzerland
* SGTE Travaux Electriques, Technoparc Gessien, rue Gustav Eiffel, 01630 Saint-Genis-Pouilly, France

This paper describes the cryogenic control system and associated instrumentation of the test facility for 3 pre-series units of the LHC Cryogenic Distribution Line. For each unit, the process automation is based on a Programmable Logic Controller implementing more than 30 closed control loops and handling alarms, interlocks and overall process management. More than 160 sensors and actuators are distributed over 150 m on a Profibus DP/PA network. Parameterization, calibration and diagnosis are remotely available through the bus.
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1 INTRODUCTION

The Large Hadron Collider (LHC), currently under construction at CERN [1], will make use of 1700 main superconducting magnets distributed along a 27 km circular tunnel and operating in superfluid helium below 2 K. A Cryogenic Distribution Line (QRL) [2], mounted in parallel to the magnets, will feed them through jumper connections every 107 m. Several thousand sensors and actuators will be mounted either on the magnets or on the QRL, scattered along the LHC circumference.

Therefore, it is important to investigate process automation based on instrumentation distributed over industrial field networks. This will simplify considerably the cabling, configuration and maintenance, compared to typical point to point connections between process controllers and field devices.

Three pre-series Test Cells of the QRL, delivered by different suppliers, will be tested during 2000 to validate their thermal and mechanical design. For each Test Cell there are more than 160 sensors and actuators, distributed over 150 m on a Profibus DP/PA network. A Programmable Logic Controller (PLC) implements 34 Closed Control Loops (CCL) and handles alarms, interlocks and the process phase sequencing. All instrumentation is accessed either through Profibus remote I/O cards or directly on Profibus DP or PA; parameterization, calibration and diagnosis are remotely available, through the bus.

2 CRYOGENIC LINE TEST FACILITY

Each QRL Test Cell [3] (~110 m length) comprises an LHC standard cryogenic distribution cell (Pipe Module) and one Service Module at each end (SI and SA). The Service Modules include the valves and jumper connections to feed later on the magnets cooling loops.

For each Test Cell, an additional set of four End Boxes is used to supply (TS) and to return (TR) cryogens to the main cooling circuits and to simulate the interfaces to the magnets (TI and TA). They house the four phase separators and control valves necessary for the Test Cell operation. In order to discriminate the heat load of the QRL Test Cell from that of the auxiliary End Boxes, the later are evaluated in a dedicated test set-up where a Link Module replaces the Test Cell.

The cryogen used to cool the Test Cell is helium, saturated at 4.2 K and gaseous at 80 K. A 10 m^3 dewar fills a phase separator in the Supply Cryostat with liquid helium, to be distributed to the three Test Cells. For pre-cooling the Test Cells, circulated helium gas will be cooled by liquid nitrogen, fed by a 50 m^3 Tank.

3 PROCESS CONTROL

The cryogenic process of each Test Cell is controlled by a PLC (Siemens® CPU413-2DP) running 34 CCL with a sampling time of 2.5 s, which is well adapted to the plant characteristics. The process management includes several phases such as cool down, nominal operation, warm-up and thermal cycling.

Software interlocks, on the liquid helium level of the End Boxes' phase separators, close the associated filling valves to prevent overflow and stop the liquid heaters when the level is too low. All other electrical heaters are software-interlocked to associated thermometers, inhibiting them at too high temperature; moreover, for high-power heaters (>1 kW) additional hardware interlocks on the actual temperature of the heating element operate independently of the PLC working status.

Alarms are provided to notify the operator when the liquid level or the gas pressure in the phase separators are too high. The test set-up can be fully automatically operated without human intervention 24 h per day. Upon an alarm occurrence the operator is warned, either by e-mail or cellular phone.

An Engineering Work Station (EWS) is used for PLC programming and configuration, parameterization and maintenance of intelligent devices. The cryogenic operation and the data storage are performed by an Operator Work Station (OWS), running PCVue32™ (Arc Informatique®) as Supervisory Application Control and Data Acquisition and directly accessing the PLC data base of process variables.

4 PROFIBUS NETWORK

Profibus is a Master-Slave serial data communication system, networking decentralized digital controllers and field devices. Masters are active stations, like the PLC or the EWS, that manage the data communication on the bus; they can take control of the bus, via token exchange, and send messages without external request. Slaves are peripheral devices such as remote I/O, valve positioners and measurement transmitters, that communicate under request. The Profibus network comprises DP and PA segments.

4.1 Profibus DP

Profibus DP, based on EN 50170 standard, is specifically dedicated to fast data exchange between automation systems and distributed peripherals. The communication medium can either be a twisted-pair shielded copper cable or an optical fiber; via the copper cable, the transmission conforms to the EIA RS485 standard, in a linear network topology. The cable length per bus segment ranges from 100 m (at 12 Mbit/s) up to 1200 m (93.75 kbit/s); the maximum number of stations per segment is 32. Using RS485 repeaters, the bus length can be extended by a factor of 10 and the number of stations increased to 127.

The DP network of each Test Cell (Figure 1) consists in a 150 m long segment, that operates at 1.5 Mbit/s and comprises 23 nodes, including EWS, PLC, DP/PA Link, 15 remote I/O stations (ET200M) and 5 Mass Flow Meters (MFM).

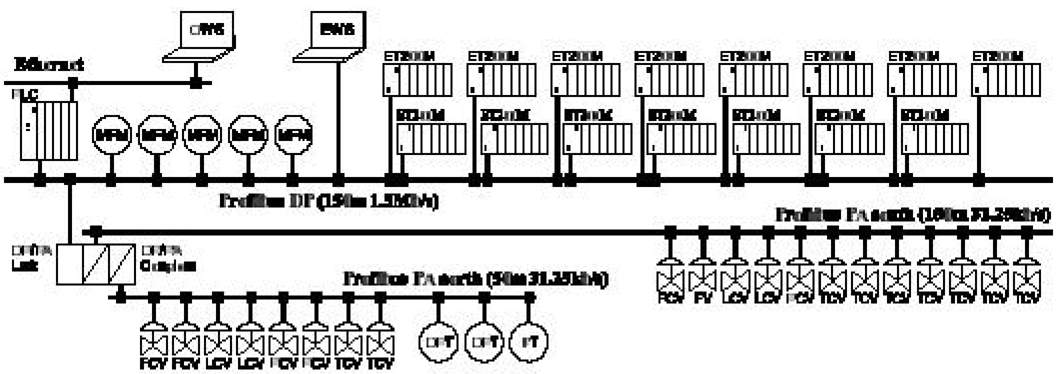

Figure 1 Field network

4.2 Profibus PA

Profibus PA is based on EN 50170, like Profibus DP, and uses a transmission technology according to the IEC 61158-2 standard, in a linear and tree network topology. It provides data communication, at 31.25 kbit/s, and power supply through the same twisted-pair shielded copper cable. The maximum cable length, including star branches, is 560 m; each branch is limited to 30 m or 120 m, according to the number of branches. The maximum number of stations in a PA network is 32.

The DP/PA Coupler (Siemens®) provides galvanic isolation and transmission technology conversion between both type of segments; communication speed on the DP side is 45.45 kbit/s. The current available to feed the stations is limited to 400 mA. The DP/PA Link (Siemens®) allows to distribute higher power consumption over up to 5 Couplers, yet on the same PA network. The number of stations is still limited to 32, but communication speed on the DP segment is no more limited to 45.45 kbit/s.

The PA network of each Test Cell consists in two linear segments, with 11 and 12 stations and a length of 50 and 150 m respectively; it includes 20 intelligent valve positioners and 3 pressure transmitters, consuming 12 and 10 mA respectively. The positioners incorporate a current consumption limitter (16 mA) to avoid blocking the bus in case of failure. A single DP/PA Link and two Couplers are used.

5 INSTRUMENTATION

The 121 sensors per Test Cell comprise 99 thermometers, 7 level-, 5 flow- and 10 pressure- transmitters. The actuators consist of 28 valves and 20 heaters, corresponding to 47 kW of controlled electrical power; among these actuators, 34 are PID-controlled whereas the others are on/off devices.

Fifteen remote I/O stations (Siemens® ET200M, Figure 2) are used for reading most of the input signals (115 analog and 58 digital) and for controlling heaters and non-intelligent valves (3 analog and 29 digital outputs); this represents 88 % of the total channel count (236). Each I/O station communicates with the PLC via Profibus DP.

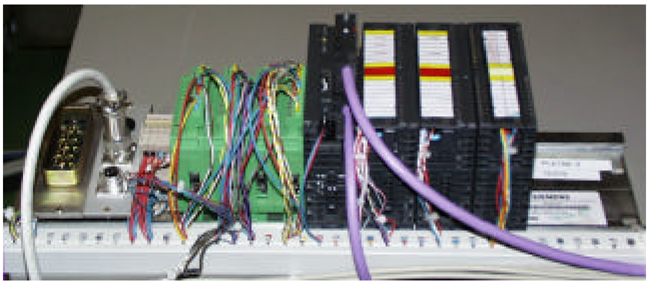

Figure 2 Conditioners and ET200M I/O

At the extremities of the Test Cell (Figure 3), two racks house the PLC, the signal conditioners for the End Boxes' thermometry and level measurement, and the associated I/O stations. Next to each of them, a relay cabinet controls the powering of the heaters.

Temperatures are measured with three types of sensors: Platinum, Carbon (AllenBradley®) and Cernox™ (LakeShore®) that cover respectively the 30...300 K, 1.6…100 K and 1.6...300 K ranges. Platinum sensors are read directly by ET200M using an R-4-wire configuration, without any intermediate signal conditioning. Cernox™ and Carbon sensors are read by CERN-developed linear multi-range signal conditioners [4], whose 4-20 mA outputs are sent to ET200M. As all these sensors are non-linear, the resistance is converted into temperature (Kelvin scale) by a linear interpolation routine running on the PLC.

Liquid helium levels in the phase separators are measured with superconducting wire gauges (Twickenham Scientific Instruments®); to minimize the dissipated heat, the sensor excitation is pulsed. Their 4-20 mA current-loop outputs are read by ET200M. Liquid nitrogen levels in the Tank and in the Subcooler are measured with differential pressure transmitters (Endress+Hauser®), communicating through Profibus PA.

Intelligent Mass-Flow Meters (MFM) (Brooks®) communicate directly on Profibus DP. The pressure on the nitrogen Tank is read by a Profibus PA transmitter (Endress+Hauser®); pressure transmitters (Danfoss®) on all the phase separators and on some pipes have 4-20 mA outputs to ET200M.

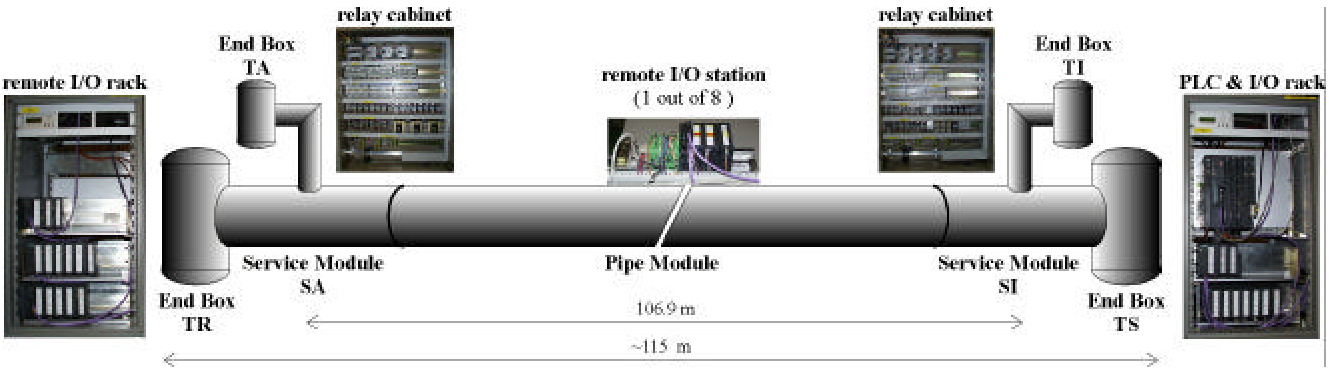

Figure 3 Layout of a QRL Test Cell, showing End Boxes, relay cabinets and instrumentation racks

The pneumatic valves (Kämmer®) with intelligent positioners (Siemens® SIPART PS2) communicate through Profibus PA. In case of loss of communication or power, the positioner drives the actuator to its fail-safe position. Furthermore, the compressed air circuit between each positioner and the respective actuator can be cut by an electromagnetic-valve; this action is simultaneous for all pneumatic valves and is driven either by a manual switch or by an ET200M digital output. Three classical analog control valves are driven with 4-20 mA (from ET200M) and have digital end-switches; five on/off valves are driven by 0/24 V digital outputs (also from ET200M).

Electrical heaters are powered through 220 V AC solid state relays, with average power regulated by pulse-width modulation technique; the relays are driven by ET200M digital outputs.

6 END BOX TEST FACILITY

A preliminary test on each of the three sets of End Boxes is being carried out (Figure 4). Due to the limited spatial extension, the DP segment is reduced to a few tens of meters, permitting operation at 12 Mbit/s. More than 40% of the full Test Cell instruments are used, including 85% of the heaters and 30% of the valves and thermometers.

During this test, the final version of both signal acquisition racks is commissioned, allowing to check the Profibus network, assess and adjust sensors' accuracy and tune PIDs and phase sequence.

Figure 4 End Boxes and Link Module

7 CONCLUSION

The process automation and field network, with distributed I/O and smart instrumentation, has been successfully implemented and commissioned for the QRL End Box test. Its extension for the full QRL Test Cell is in progress.

As for another Profibus network formerly implemented at CERN [5], the commissioning of the remote I/O and intelligent valve positioners was straightforward. However, despite being on the market for already one year, certain DP intelligent devices still show some problems. Occasionally, power interruption leads to permanent device malfunction, with communication loss or bus jamming, possibly due to galvanic isolation issues. This can be circumvented by using their 4-20 mA output. Moreover, the functionality is not yet as advertised by the manufacturer: a missing function was fixed on the configuration file but not on the device firmware. Bad electrical contacts on internal connectors have been solved by the replacement of connector type. Interaction with the manufacturer is going on to solve these troubles.

The utilization of a Profibus DP trace monitor software, running on the EWS, has been helpful to visualize the availability of devices and the data exchange between partners in the network. Process Device Manager (Siemens® PDM) has been used for configuration and parameterization of the PA devices. Its current version is limited to 16 nodes and only runs on a EWS connected to the DP bus and to the PLC. A new release with unrestricted number of devices and access not limited to Profibus will soon be used.

Connection to PLC through the Local Area Network and the interoperation of the PLCs of different Test Cells are under consideration.

REFERENCES

1. The LHC Study Group, The Large Hadron Collider Conceptual Design, CERN/AC/95-05.
2. Erdt, W.K., Riddone, G., Trant, R. The Cryogenic Distribution Line for the LHC: Functional Specification and Conceptual Design, In: Proc. CEC/ICMC99, Montreal, Canada.
3. Livran, J., Mouron, G., Parente, C., Ridonne, G., Rybkowski, D., Veillet, N. A Cryogenic Test Setup for the Qualification of Pre-series Units for the LHC Cryogenic Distribution Line, paper presented at this conference.
4. Casas, J., Gomes, P., Henrichsen, K.N., Jordung, U., Rodriguez-Ruiz, M.A. Signal Conditioning for Cryogenic Thermometry in the LHC, In: Proc. CEC/ICMC99, Montreal, Canada.
5. Casas, J., Gomes, P., Jordung, U., Metral, L., Serio, L., Suraci A. Process Automation of a 600 A HTS Current Lead Cryogenic Test Facility Using a Field Network with Smart Instrumentation, In: Proc. ICALEPCS99, Trieste, Italy.