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EXPERIENCE IN CONFIGURATION, IMPLEMENTATION AND COMMISSIONING OF A LARGE SCALE CONTROL SYSTEM (BASED ON LHC CRYOGENIC DISTRIBUTION CONTROL SYSTEM)

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Abstract: This paper presents three years' experience on configuration, implementation and commissioning of the Cryogenic Distribution Control System (CDCS) for the Large Hadron Collider. CDCS is based on 18 Programmable Logic Controllers, each serving up to 2 000 IOs, distributed in eight 3.3 km long sectors and two Accelerator Superconducting Cavities. Large scale and complexity of the control system forced development of several test procedures which allow validating each of the three standard hierarchical control system layers. The commissioning of the various sensors with infrastructure has been done by a Mobile Test Bench. Different types of actuators have been parameterized and their operationality has been checked in the field. Tests of remote IO modules and communication field buses have been performed using a portable PLC. For final check of all pneumatic actuators, an automatic test procedure has been implemented. Synoptic and tunnel coherence test has been performed to validate all control system layers.

Key words: control systems, instrumentation, commissioning, cryogenics, LHC

1 LHC Cryogenic Distribution Control System - Function and Structure

Large Hadron Collider (LHC), the world's highest energy particle collider, is now being completed in European Organization for Nuclear Research (CERN). This proton-proton collider housed in the 27 km circumference tunnel is designed to provide proton collisions at 14 TeV in the centre of mass. LHC will provide information about the structure of matter on terascale (energy range 1 TeV involved) and energy in the universe. To control the proton beams, the LHC will use hundreds of superconducting magnets which have to be cooled with superfluid helium at 1.9K (-271˚C).

The LHC cryogenic system consists of two main parts. Gas storage, warm compressors and refrigerators located on the surface, cold compressors located in underground caverns together with interconnection boxes are responsible for supplying LHC with liquid helium. Tunnel cryogenic distribution line (QRL) redistributes cooling capacity around the ring and constitutes production process.

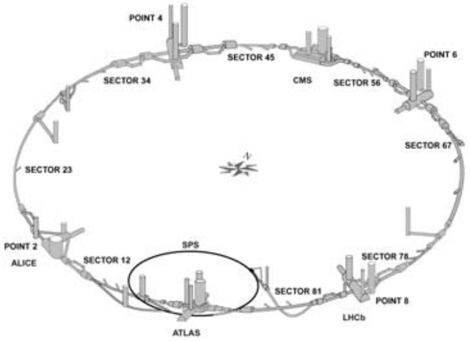

Fig. 1. Large Hadron Collider

Liquid helium fills magnet cold masses housed in cryostats, Distribution Feed Boxes (DFB) and Accelerator Superconducting Cavities (ACS).

The Cryogenic Distribution Control System (CDCS) is one of several systems required by LHC accelerator to be operational [Brüning et al., 2004]. For the cryogenics to perform operation and start cool-down of up to 1804 superconducting magnets (37600 tonnes of cold mass) distributed in the tunnel it is required to obtain the readiness signal from the vacuum control system. When magnets reach stable temperature below 2K the CDCS gives the signal triggers for powering the magnets circuit.

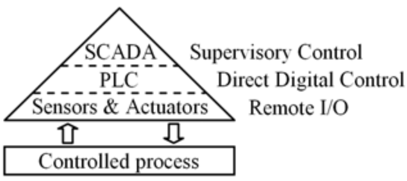

Fig. 2. Control system layers

The CDCS is composed of three hierarchical layers (Fig. 2). The remote I/O layer provides the information about current process status to the upper level. Usually this information comes as readouts of various types of sensors e.g. temperature, pressure, and liquid helium level. Simultaneously this layer sends orders from upper level to the process through actuators. In cryogenics we come across two types of devices performing this function: valves and heaters. The middle layer is responsible for Direct Digital Control (DDC) and is supported by Programmable Logic Controllers (PLC). According to project design controllers work in real time where sampling period required is not smaller then 100 ms [Brüning et al., 2004]. PLCs programs contain up to 3873 Closed Control Loops (CCL) with modular PID algorithm. Whole process logic is divided in 12 phases using sequential control, reflecting LHC cryogenics. The supervisory layer is an interface between human and the process. It includes standard attributes of the Supervisory Control and Data Acquisition system (SCADA): process synoptics, alarms and interlocks handling, event logging and archiving, real-time and historical trends, navigation and global operation tools. The SCADA and data servers run under Linux operating system and provide the information for the Operator Work Station (OWS) and Engineering Work Station (EWS) clients which can be either Linux or Windows stations. All the layers are communicated by the CERN Technical Network using Profibus DP/PA, WorldFip fieldbuses and Ethernet for supervision middleware.

To keep cryogenic process operational about 15000 sensor and actuators have been installed in the LHC tunnel. All the cryogenic instruments are exposed to radiation. To reduce the noise coming from work environment sensor readout method have been designed as 4 wire resistance measurement.

The cryogenic process requires three types of real measured values: temperature, pressure and liquid helium level. For the temperature measurements two types of thermometers have been chosen: Cernox Resistance Temperature Detector (each with individual calibration table) very precise in low temperature range (sensor uncertainty is 5mK at 2K) and PT100 Platinum Resistance Thermometers with sufficient accuracy over a wide temperature range (from -200 to +850 °C). In total CDCS has 7077 thermometers installed in the LHC tunnel. For the pressure measurements 854 Baumer® sensors are used. In this type of sensor a metallic membrane is used which deformation is relative to the resistance of the extensometer bridge. Liquid helium level measurements are conducted using 436 superconductor gauges installed in the LHC machine.

Helium distribution requires special cryogenic valves due to unique work environment. The intelligent digital positioner with an actuator forms a valve control system. The current position of the valve is detected by a servo potentiometer or end switches. Two main types of valves can be distinguished: Control Valves (CV) that can be regulated in a range of 0 to 100% (analog valves), Quench and Pressure Valves (QV, PV) that have only two states either opened or closed (digital valves). There are 2606 CVs, 341 QVs and 339 PVs in the cryogenic distribution line. Where relevant, radiation sensitive parts of valves were disassembled and moved to protected areas (alcoves). Beside valves another actuators used in cryogenics are 2361 heaters. Most heaters are built with resistant wire and protection temperature sensor covered with insulating foil. The heaters are placed on the cryogenic pipe elements or inside the magnet cryostats. Their heating power ranges from 25W to 500W.

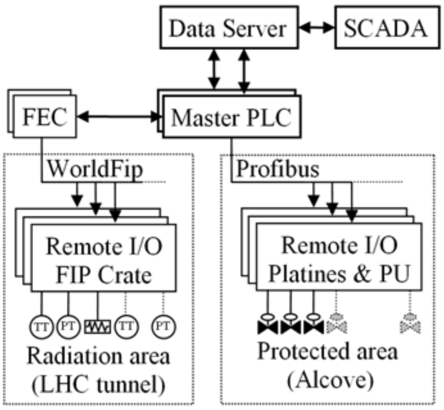

Fig. 3. Cryogenic Distribution Control System Structure

Two fieldbuses are used in the LHC accelerator to connect equipment located in the tunnel: WorldFIP and Profibus. The WorldFIP connects remote I/O crates in areas exposed to radiation because of its good resistance to electromagnetic noise and high radiation tolerance. It is based on robust semiconductors and a magnetic coupling ensuring galvanic isolation. Link between the WorldFip and master PLC is provided by Front End Computer (FEC). Profibus, connecting remote I/O Platines (boards housing electronic equipment) in protected areas was chosen because of its simplicity of configuration and flexibility. The length of fieldbus is up to 3.3km. Fig. 3 shows the typical structure of the cryogenic control system for one of the 8 LHC sectors.

2 Configuration, Implementation and Commissioning

In order to perform the commissioning of the cryogenic instrumentation, four Mobile Test Benches (MTB) have been built and several test procedures have been designed for actuators validation.

2.1 WorldFIP equipment

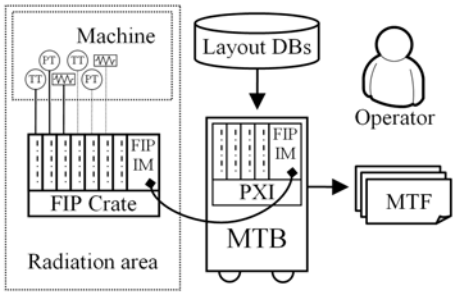

Fig. 4. Mobile Test Bench testing

MTB (Fig. 4) is custom automatic test equipment designed to perform tests of WorldFIP remote I/O crates (housing front-end electronics: inputs with conditioner cards, output cards powering electric heaters, and WorldFIP communication interface) as well as sensors (PT, TT, and LT) and actuators (heaters) attached to them.

The MTB has integrated industrial PXI modular computer with several I/O modules, precise measuring components, power sources and a switching matrix. This enables MTB to perform tests in wide range of configurations by setting electrical connections between internal modules and front panel connectors of MTB programmatically. Whole testing system has been implemented in LabView® platform.

The commissioning of crates is semi-automated. Crate is a fully configurable object, with a definition of all cards installed inside, their position, configuration, channels and instruments connected to each channel. Those definitions are obtained by the MTB from the Layout Database to set up the testing sequence dedicated for the selected crate. Testing procedure is divided in two main steps. During the commissioning the operator has to follow directives of MTB user interface, although the software allows for some flexibility in second part.

First part, the Consistency Test, checks whether there is a correlation between crate description stored in the Layout Database and the components installed in the crate. The crate is selected by entering its ID number in MTB user interface then the operator scans all the cards barcodes belonging to the crate with a bar code reader. During this test the communication module of the crate is checked. Positive result is necessary for the MTB to continue examination.

Second part is the Electrical Test that contains 4 particular parts:

Instrumentation test verifies the following elements for every sensor and heater: physical existence, proper wiring and connection, and resistance value expected for the chosen instrument type according to measurement conditions (temperature and pressure).

Verification of the electrical connection between sensors and crates, accomplished by resistance measurement of the cable. This allows detecting of any electrically measurable problems like short circuits or gaps in wiring.

Validation of the correct functionality for each electronic card housed in the crate. The check of input cards is done by simulating the sensor on the input of the card by the reference resistor and measuring the values through the WorldFIP fieldbus. The output cards verification requires the MTB to send the request to the crate and measure the readout of the card using the onboard digital multimeter.

The last test performed during the MTB procedure checks all the components together. During this examination MTB reads feedback values through WorldFIP bus only and verifies whether the operator properly plugged back the connectors.

All test results are stored automatically in Manufacturing and Test Equipment (MTF) data base.

2.2 Profibus equipment

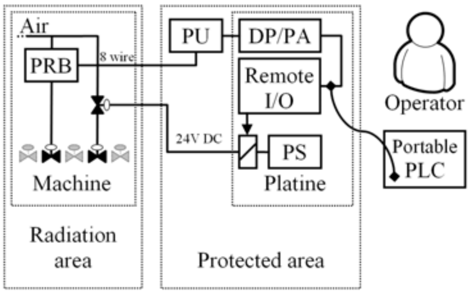

Fig. 5. Portable PLC testing

Intelligent digital positioner operates the analog valve and it was required to divide it in two parts. First, called positioner unit (PU), was placed in the radiation protected area while second, called pressure regulation block (PRB), was placed on the corresponding pneumatic actuator. Radiation tolerant equipment, regulating the pressure of the valve, comprises the potentiometer, that reads the stem position, and 2 piezo-valves, that pressurize and depressurize the pneumatic actuator. Digital valves do not contain the positioning electronics therefore the radiation protection is not relevant. The valve is driven by pressurized air supplied by additional 24V DC powered valve (cf. Fig.5).

Designed valve test procedures are divided in two independent stages: first executed in laboratory, second in the LHC tunnel.

Before installation in the LHC tunnel all valve positioner units were configured and tested in laboratory. For each positioner unit it was required to set up the following parameters: valve type, angle of feedback, travel range, safety position, station and channel address. After configuration preliminary automatic initialization with reference valve was done. The automatic initialization is a series of internal tests performed by microcontroller to determine the direction of control action and travel time as well as calibrate the zero point and stroke. Acquired results determine and optimize the control. In order to identify faulty positioner units the initialization results were compared with reference data.

After the positioner units had been installed in LHC radiation protected areas, verification procedure was executed and pressurized air was supplied. To minimize risk of later error all earlier set up parameters were checked again and main automatic initialization with target valve was done. The electrical connections between positioner unit and pressure regulation block, correct motion direction and minimum-maximum positions were verified using manual operation of each analog valve.

For the digital valves to become operational DC power supply must have been precisely regulated to obtain the value of 24V even for the valve placed farthest from power supplier (PS) localized in the radiation protected area. For the valves positioned closer suitable resistors were used. Subsequently the pressurized air was supplied. Digital valves were verified by the use of tool simulating the driving signal. Using the same technique the end switches, representing the pneumatic actuator position status, were also checked where needed.

All test results were archived in a database for future reference.

Positioner units of analog valves mentioned above are connected to the Profibus DP through the DP/PA coupler module, while the controlling signal for digital valves is provided by Profibus remote I/O module. For all Profibus modules (housed in a Platine) installation, parametrization and testing procedure was executed. Prior to the installation in the tunnel, the Platines were electrically tested in the laboratory and installed in radiation protected areas where addresses and network topology were configured. After that the whole remote I/O layer could be examined. In order to perform this verification portable PLC has been set up and connected to the fieldbus. The 34 particular hardware configurations of the instrumentation infrastructure for the portable PLC have been manually prepared on the basis of the Layout Database. During the test each Remote I/O and DP/PA coupler modules were connected to the Profibus network in order to ensure consistency between the database and physically installed components for the following parameters: type, version, address, and number of modules. Afterwards for each digital valve its channel assignment on the remote I/O module was checked. Similarly for the analog valves the Profibus PA address was validated on the DP/PA coupler level.

Positive results of previous tests are required to integrate the remote I/O distributed in the tunnel with the master PLC located in Control Room on surface. This connection is realized by the fibre optics.

2.3 Automatic valve test procedure

After configuration and verification on hardware level and accessibility check of each control system component integrated with the master PLC extensive tests of actuators operability have been performed. Considering the large scale of developed system, it was necessary to develop test procedure that would allow fast and detailed evaluation of each actuator. Such tests could be performed only on devices that provided hardware feedback therefore most of analog and digital valves are tested. Because there was no necessity to test the heaters the test procedure for them has not been developed.

Developed automatic test procedure of a valve is aimed to repeatedly check its reaction time and precision to requests sent by PLC. Procedure has been implemented as a part of PLC program, and can be activated any time for a specified period by a qualified engineer. The default period has been defined as time needed for a valve to open and close 100 times. For each type of tested device dedicated procedure was developed that gives possibly complete information about condition of device. Timing of requested value implemented in test algorithms was selected accordingly to valve documentation, for proper verification of device's reactions as well as to minimize the time required to obtain the results.

Cycle of the test for the analog valve consists of 100 s valve opening period with 1%/s ramping, 50 s pause and 100 s valve closing period with the same ramping followed by another 50 s pause. Analog valves provide feedback information about their current position. Every second for each tested valve a number of checks are performed e.g.: occurrence of the IO-error, valve's reaction time, request-feedback difference (must be less than 15%), feedback position range (-2.5% ÷102.5%).

Test cycle for digital valves is similar to analog and the difference is the requested position which is either opened or closed. Due to this only the position and time when it was reached (must be less than 5s) are verified.

Detection of any error mentioned above is registered as a number of occurrences of each error type. During the test all information is gathered in the PLC and copied afterwards to dedicated spreadsheet, prepared for future analysis.

2.4 Valve coherence test

The final stage of hardware commissioning is the coherence test concerning all system valves using all three system layers. Remote I/O, PLC and SCADA are thoroughly checked during this procedure. In order to perform the test a complete SCADA system with process synoptic panels is required. The panels are created on the basis of machine technical drawings and information collected in the Layout Database.

Aim of this test is to verify in the tunnel if requested valve responds correctly. Verification procedure must be done by a team: operator, responsible for sending requests and checking feedbacks on the supervisory system, and technician present in front of tested valve.

Heaters coherence test is finalized during preliminary machine run due to equipment nominal parameters e.g. temperature.

3 Conclusions

Procedures described in this paper were necessary for validating a large scale control system. The CDCS components for each of 8 LHC sectors have been successfully configured, implemented and commissioned according to those methods. Their main advantages are deployment time reduction and improved reliability of the control system. Furthermore, these methods can be used during long term CDCS machine maintenance making it simpler, safer and more effective.

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