PROCESS AUTOMATION OF A 600 A HTS CURRENT LEAD CRYOGENIC TEST FACILITY USING A FIELD NETWORK WITH SMART INSTRUMENTATION

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Abstract

This paper reports on the control system of a cryogenic test facility for High Temperature Superconducting current leads (HTS600). The control system is based on a Programmable Logic Controller (PLC) implementing 22 Closed Control Loops (CCL), and a Profibus DP/PA network interconnecting 53 sensors and actuators from different manufacturers. These devices can be calibrated and parameterised remotely through the Profibus network. This is the first complex Profibus DP and PA network that has been implemented and commissioned at CERN.

1 INTRODUCTION

The Large Hadron Collider (LHC) currently under construction at CERN will make use of 1700 main superconducting magnets distributed around the 27 km tunnel, operating in superfluid helium below 2 K [1].

Several thousand sensors and actuators will be installed throughout the tunnel. Therefore it is crucial to investigate the utilisation of field networks. Such networks should provide considerable simplification in the conventional cabling and maintenance requirements, compared with typical point to point connections between controllers and field devices.

The HTS600 was chosen as a pilot project to evaluate the performance and compatibility of both hardware and software solutions offered by industry for field networks, integrated within a typical LHC cryogenic control system.

Although geographically concentrated (Figure 1), the type and diversity of sensors, actuators and control loops found in the control system for the HTS600 are representative of the foreseen LHC cryogenic control plant.

2 TEST SET-UP

A low heat-inleak cryogenic station (Figure 2) for testing the 600 A HTS current leads was designed in order to assess their thermal and electrical performance. The cryogenic system and the process are similar to the test set-up used for 13 kA HTS current leads, described in a previous paper [2]. It provides the required working conditions:

- 4.5 K liquid He bath, to cool down the bottom part of the HTS leads;
- up to 4 x 0.07 g/s of 20 K helium gas, to cool down the resistive part of the current leads;
- warm gaseous He, to quench the HTS part;
- recovery of gaseous He;
- instrumentation for control and diagnostic measurements.

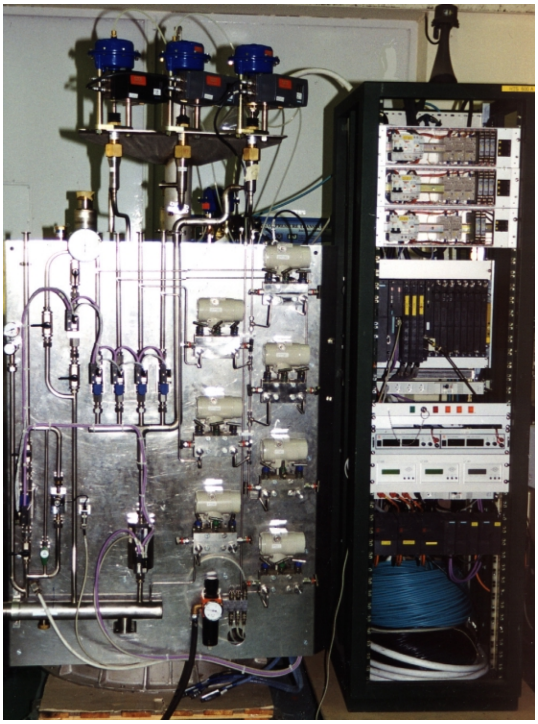

Figure 1: Instrumentation on Profibus DP and PA and control rack

3 INSTRUMENTATION AND PROCESS CONTROL

3.1 Instrumentation

The remote I/O system (ET200M from Siemens) is used for acquiring all analogue and digital signals and for controlling classical actuators like heaters or valves (Figure 2). This represents 65% of the total instrumentation. It communicates with the PLC via Profibus DP.

The temperatures used for monitoring and control are measured with two types of sensors: Platinum and Cernox™ (from Lakeshore) that cover respectively the 300 K to 25 K and 300 K to 4.2 K ranges.

The HTS current leads being developed for the LHC are rated to withstand voltage levels up to 3.2 kV and a suitable galvanic isolation is required for lead temperature measurement. IPAC-4L™ signal conditioners (from Inor) are used to provide 5 kV galvanic isolation.

Cernox™ sensors are read by CERN-developed linear multi-range signal conditioners [3].

Liquid He levels in both cryostats are measured with superconducting wire gauges (from Twickenham). To minimise the dissipated heat, the sensor excitation is pulsed.

The 4-20mA current-loop outputs from thermometer signal conditioners and from the level gauges are read by ET200M.

Platinum sensors not requiring high-voltage isolation are read directly by ET200M using a 4-wire configuration, without any intermediate signal conditioning.

Electrical heaters are used to warm-up cold gaseous He exiting the cryogenic station. They are powered through 220 V ac solid state relays and the power is adjusted using a pulse-width modulation technique. The relays are driven by ET200M digital outputs.

Intelligent mass-flow meters (MFM) and mass-flow controllers (MFC) (from Brooks) are used to assess the thermal performance of the test set-up and of the current leads and to control the flow rates. They communicate with the PLC through Profibus DP.

Pneumatic valves (from Weka), with intelligent positioners (SIPART PS2 from Arca/Siemens) are used for filling and emptying the cryostats.

Differential pressure transmitters (from ABB) measure the pressure drop along the resistive part of the leads. Absolute pressure transmitters (from ABB) are used to control the pressure of the helium baths and to monitor the He recovery line.

Both the intelligent positioners and the pressure transmitters communicate with the PLC through Profibus PA and a DP/PA coupler.

3.2 Process Control

The process is controlled by a PLC (CPU 413-2DP from Siemens) taking care of 22 CCL, alarms, interlocks and the overall process control. The control loops sampling time (2 s) is adapted to the plant characteristics.

The process control includes several phases such as cool down, normal operation, quench and warm up. The test set-up can be operated without human intervention 24 h per day. In case of an alarm, the operator is automatically called, either by e-mail or cellular phone.

Interlocks with the high-current powering system are necessary to prevent current lead damage; the most critical interlock parameters are related to the liquid He level and the temperature of the junction between the normal and HTS parts of the leads. Furthermore, leads powering is not enabled until certain cryogenic conditions are satisfied.

As cryogenic temperature sensors are highly nonlinear, their resistance is converted into temperature (Kelvin) by a linear interpolation routine.

The cryogenic operation and the data acquisition are made by an Operator WorkStation (OWS), running PCVue32™ as SCADA (Supervisory Application Control and Data Acquisition).

The Engineering WorkStation (EWS) is used for PLC programming and for intelligent devices configuration, parameterisation and maintenance.

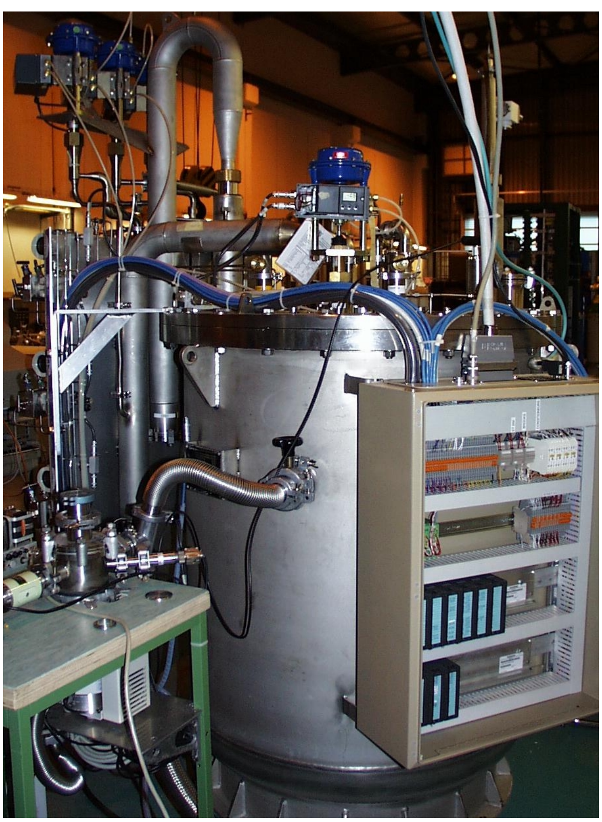

Figure 2: overview of the cryostat and remote I/O

4 COMMUNICATION NETWORK

Figure 3 shows the entire data communication network composed of three different parts: Industrial Ethernet, Profibus DP and Profibus PA.

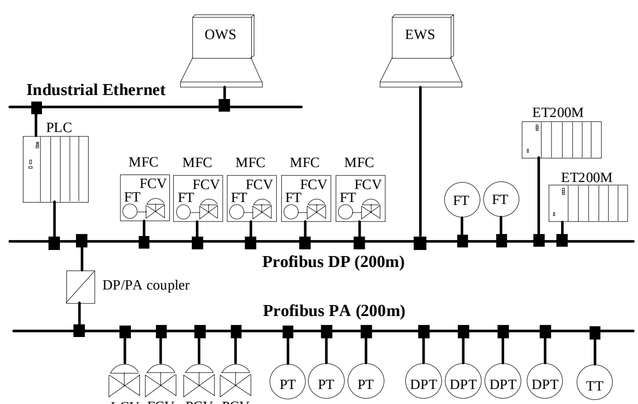

Figure 3: communication network

4.1 Industrial Ethernet

Industrial Ethernet is used as local area networking between the PLC and the OWS, which can be located in any part of the CERN computer network. A local server is used for storing long-term data.

4.2 Profibus

Profibus specifies the technical and functional characteristics of a Master-Slave serial data communication system, with which decentralised digital controllers and field devices can be networked.

Masters, as active stations, determine the data communication on the bus. They can send messages without external request via "token" utilisation. Slaves are peripheral devices such as valves and measurement transmitters.

The Profibus network comprises DP and PA segments. Examples of DP stations are ET200M remote I/O, DP/PA Couplers, MFM and MFC, and the EWS. The PA stations include pressure and temperature transmitters, and intelligent valve positioners.

Problems in Profibus communication may result in a crash of the PLC, if the proper error handling routines are not programmed. To avoid signal reflection, DP and PA need proper cable termination at both ends. Care is required with connector assembly, grounding and shielding.

4.2 1 Profibus DP

Profibus DP (based on EN 50170 standard) is specifically dedicated to fast communication between automation systems and distributed peripherals. The transmission medium can be either twisted-pair shielded copper cable or optical fibber.

Transmission over copper cable uses a transmission technology according to the EIA RS485 standard, in a linear network topology. The maximum copper cable length per bus segment ranges from 100 m, for 12 Mbit/s, up to 1200 m, for 93.75 kbit/s. The maximum number of stations per segment is 32. Using RS485 repeaters, the bus length can be extended up to 10 times and the number of stations increased to 127.

In order to validate the system on long distance, approaching the LHC tunnel conditions, the HTS600 DP network consists in a 200 m long segment, operating at 1.5 Mbit/s and using halogen-free copper cable. It comprises 12 nodes, including: PLC, EWS, ET200M, as well as MFM and MFC.

The commissioning of the remote I/O and the PLC was straightforward. However, for the DP intelligent devices some problems were encountered such as: poor quality control (unplugged electronic chips), missing functionality (flow totaliser not available) and too many GSD (parameterisation) file versions in circulation.

The utilisation of a Profibus trace monitor software, running on the EWS, has been helpful to visualise the availability of devices and the data exchange between partners in the network.

4.2.2 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; furthermore, each branch is limited to 120 m or 30 m, according to the number of branches. The maximum number of stations in a PA network is 32.

The DP/PA Coupler (from Siemens) provides galvanic isolation and transmission technology conversion between both networks; 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 (from Siemens) allows to distribute a higher power consumption over up to 5 Couplers, yet on the same PA network. The number of stations is still limited to 32, but DP communication speed is increased from 45.45 kbit/s to up to 12 Mbit/s.

On HTS600, the 200 m long PA network consists on 12 stations consuming less than 400mA (Table 1); a single Coupler is thus enough. However, a DP/PA Link is used to allow DP communication above 45.45 kbit/s.

Some of the PA devices used in HTS600 have a current consumption limitter in case of failure; devices without this feature may just block the bus when malfunctioning.

Table 1: Nominal current consumption for the PA devices

7 x ABB pressure transmitters	7 x 12 mA
4 x SIPART PS2 valve actuators	4 x 20 mA
1 x SITANS T3K PA	1 x 11 mA
total	175 mA

Process Device Manager (PDM from Siemens) is a configuration and parameterisation software for PA devices. Unfortunately, for the moment it only runs on a EWS connected to the DP bus, not to Ethernet.

During the commissioning of both SIPART PS2 and ABB devices, the support team from Siemens-Karlsruhe was very helpful in building and debugging several beta-versions of PDM. Support on site was given by ABB for the commissioning of the pressure transmitters.

5 CONCLUSION

A field network with smart instrumentation has been successfully implemented and commissioned at CERN, for the HTS 600A current leads cryogenic test facility.

As this is the first complex Profibus network installed at CERN, it is not surprising the amount of difficulties encountered during its installation and commissioning. Many of the devices offered on the market are often close to prototypes and sometimes the configuration files are not up to date. The Profibus network is not as mature as the literature claims, although it is developing at a very fast pace. The main advantages of using a field network are simplified wiring, parameterisation and maintenance.

The field network to be used in the LHC, should also be radiation tolerant. An evaluation of various fieldbus technologies under radiation is currently under way.

REFERENCES

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