THE CONTROL AND DATA ACQUISITION OF THE LHC TEST STRING

R.Saban, D.Brahy, J.Casas-Cubillos, M.Grippeling, D.Lavielle,
G.Leo, L.Madaro, A.Rijllart, M.Skiadelli
AT Division CERN, 1211 Geneva 23

I. INTRODUCTION

In 1994, CERN built and commissioned the first version of the LHC Test String [1]. It was composed of one quadrupole and two 10-m long twin aperture dipole magnets. During the shutdown last summer, one extra dipole magnet was added. As for the Accelerator Systems String Test [2] at SSC, the objective of the LHC Test String is to study the phenomena which can be observed only when the components are assembled into an LHC subsystem.

A. The organization of the runs

The first experimental run started in February 1995 and lasted until mid June. The first part of the run included cryogenic system commissioning [3], sensor calibrations, and power system commissioning to validate the magnet protection system. The experimental programme that followed produced results leading to a modified machine design (number of quench relief valves), validated the quench detection and magnet protection system [4] and left some questions unanswered (quench propagation). The String Team, which consists of one specialist in each field (controls, cryogenics, data acquisition, powering, mechanics, survey and vacuum) ensures the correct operation of the equipment for the duration of the experiment. It also makes sure that the experiment yields the required data. The Experiment Committee approves experiments and sets their priority. Both the String Team and the Experiment Committee report to the LHC Steering Committee on Magnets and Cryogenics.

B. The Systems

The LHC Test String is supported by a number of systems. The vacuum system [5] includes a number of gauges, pumps and gas analyzers. It maintains the insulation vacuum, which is essential for cryogenic operation, to a few 10^{-6} mbar when the LHC Test String is cold and evacuates the beam pipes to around 10^{-9} mbar.

The cryogenic system consists of a Cool-down and Warm-up Unit (CWU) and a String Feed Box (SFB) which handle the cryogenic fluids necessary for operating the LHC Test String. The main operational phases of the cryogenic system are:

- cool-down from 300 to 80 K ,
- warm-up to 300 K; both these actions use gaseous helium supplied by the CWU. The helium temperature is set according to a gradient across the LHC Test String,
- cool-down to 4.5 K and magnet filling: supercritical helium is expanded inside the magnets until the temperature reaches 4.5 K at the last magnet; at this moment the magnets are full with liquid helium at 4.5 K,
- cool-down to 1.8 K and normal operation: saturated superfluid liquid helium removes the heat from the pressurized helium inside the magnets via a longitudinal heat exchanger which runs along the magnets,
- recovery from a quench.

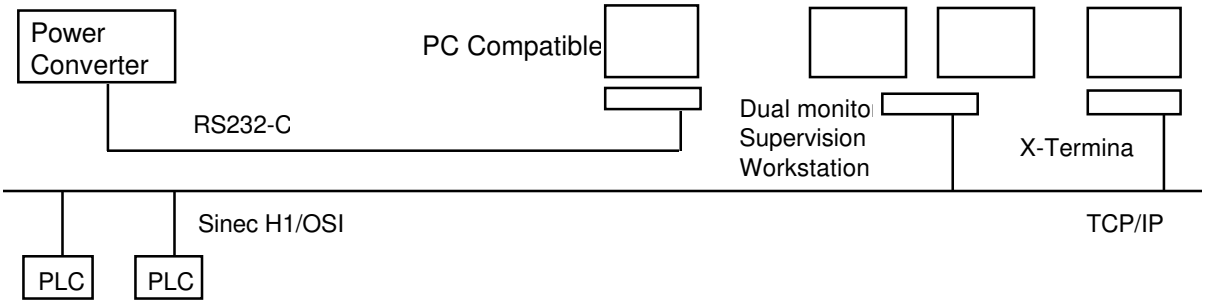
The powering system of the LHC Test String consists of a power converter with an internal current regulation loop, two switches that can open the circuit between the power converter and the LHC Test String and a quench detection system. The latter is designed to protect the magnets in case of quench.

Due to limited manpower, the utmost care has been taken to make use of standard industrial practice in controls and hence to adapt the specification for a commercial offer. For the data acquisition, a technical specification was written and the system was purchased as a turn-key one from industry.

II. THE CONTROL SYSTEM

In line with the current trends at CERN [6,7], a control strategy similar to ones used in industry for manufacturing and for continuos processes was adopted. Whenever possible in-house developments were

avoided. This resulted in a control system architecture based on industry standard Programmable Logic Controllers (PLC) which are interfaced to the operators via an industrial network and a commercial supervision software package running on a commercial computer platform.



A. The Process Control

Two very different approaches were adopted for implementing the process control of the LHC Test String. Both are based on the same brand of commercial PLCs.

The first consisted of ordering the process control as an integral part of the turn-key cryogenic equipment: the technical specification [8] mentioned that the use of a certain brand of PLCs would be considered an advantage and that the details of the communications between the PLCs and the supervision had to be agreed between CERN and the supplier. This approach proved very efficient because while leaving the responsibility for the performance of the equipment with the supplier, CERN could influence the choice of the control hardware and software to take full advantage of installed infrastructures and in-house knowledge. Additionally, since the PLC brand was a widely used commercial product, no extra burden was placed on the supplier. This approach was used for example for the CWU.

The second approach consisted of using industrial process control hardware and software of the same brand as the equipment mentioned earlier, but carrying out the integration, installation and programming in-house. Despite insufficient man-power, this approach proved necessary in two instances: the LHC Test String Cryogenic Feed Box control and the Vacuum monitoring. Particularly in the case of the former, the equipment to be controlled was too prototypical to be described in a technical specification and frequent modifications were needed for its evolution.

B. The Supervision

The supervision of the installation was implemented using a commercial industrial supervision package [9]. Monitoring the process was made possible via animated synoptics and trend curves; control was achieved by a mouse click on the element to be controlled: a window specific to the element is displayed and the operator enters the parameter values.

The process as a whole is surveyed by an alarm manager which receives the alarms from the field, informs the operator by a beep and displays the alarms on a table where they can be viewed and acknowledged. Additionally, the supervision package generates and keeps journal files which represent snapshots of system parameters and alarms every minute.

On the PLC side, the supervision package gathers values of field parameters using the PLC manufacturer's own protocol [10] over ethernet. Drivers for this protocol, which is based on the different ISO standards of the OSI seven layer model, were purchased with the supervision package.

C. The Supervision of the Power Converter

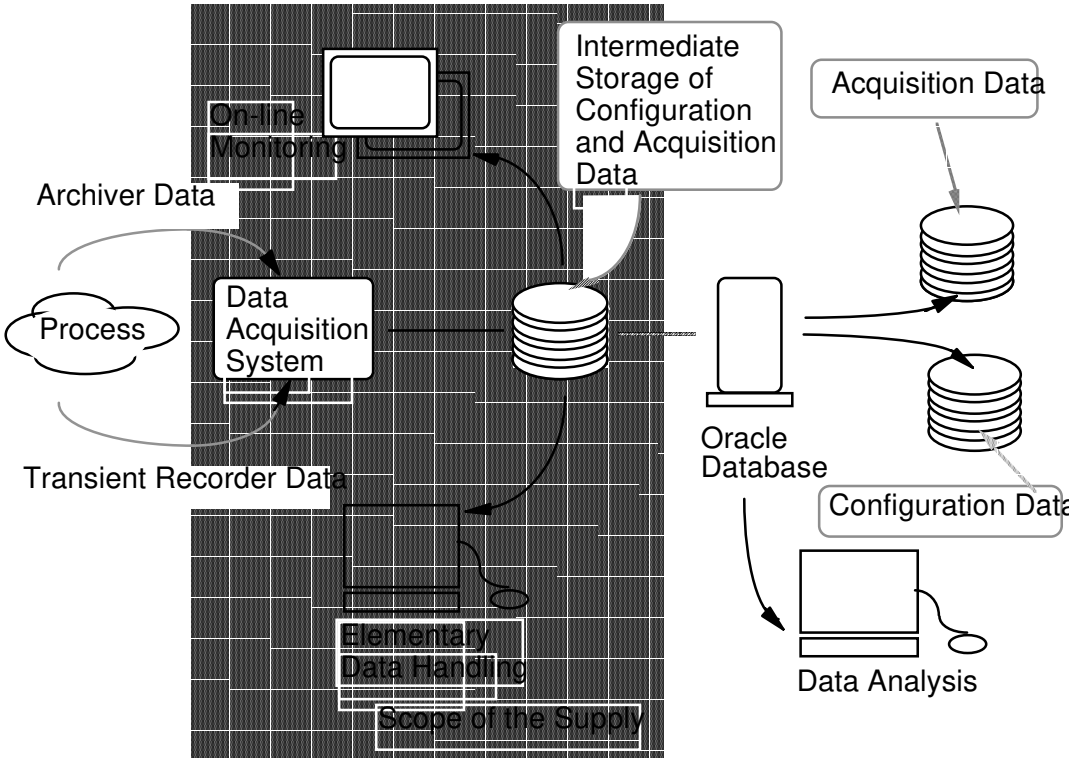
The power converter was supplied with embedded controls based on VME. From the controls point of view, it was an in-house development readily available that was already used in LEP and on other test installations used for LHC superconducting magnet tests and R&D. The supervision in the latter case had already been implemented using a commercial application enabler [11]. We adopted the same solution for the String. A PC is linked via an RS232-C serial link to a module in the VME crate. The embedded software obeys a protocol which allows the application to control, monitor and log the electrical current being supplied to the superconducting magnets of the LHC Test String.

III. THE DATA ACQUISITION SYSTEM

The specification of the data acquisition needs for the people responsible for the equipment and for the experimenters was defined in a long series of meetings held over a period of more than one year. This allowed the drawing-up of a technical specification for a common system [12].

A.The requirements

The users expressed needs on the one hand for an *archiver* which would continuously record all process parameters at 1 Hz and, on the other hand, for a *transient recorder* which would take snapshots of system variables during a quench at up to 1 kHz. This system had to be dimensioned for 500 inputs and had to allow for a doubling of its capacity.



Tenders for the project were requested from industry and the solution proposed by the lowest bidder was accepted. A detailed calendar with milestones and written test procedures was prepared and agreed to by the contracted supplier. The milestones included the acceptance of the functional analysis, tests at the works on a reduced size system, tests at the works on a full sized system, commissioning and provisional acceptance tests. Both the hardware and the software were to be supplied, together with the commissioning and a two year guarantee.

B.The Architecture

The system is based on 3 VME crates each containing 18 8-channel 16-bit 1 kHz ADC modules, one CPU and one MXI-VME [13] interface. A dual monitor Unix® workstation running a LabView® application was proposed to act as the man-machine interface for control and monitoring of the data acquisition system and as a configuration management tool. The three front-end CPUs record every input channel every millisecond and deposit the values into a circular buffer.

C.Functionality

The archiver examines one value in one thousand in the circular buffer (i.e. one value per second) and compares it with the previously recorded value; only if they differ by more than a predetermined value (ε) will the newly read value be stored. For user comfort, the value for each input is automatically stored every ten minutes.

For each input channel, the transient recorder can distinguish between three different recording intervals and operates at two possible recording frequencies. In the pre-trigger interval and the first post-trigger interval the input channel is usually sampled at the highest frequency. In the last post-trigger interval, sampling occurs at a lower frequency: this is a consequence of the relatively longer time necessary for most signals to recover from a strong perturbation.

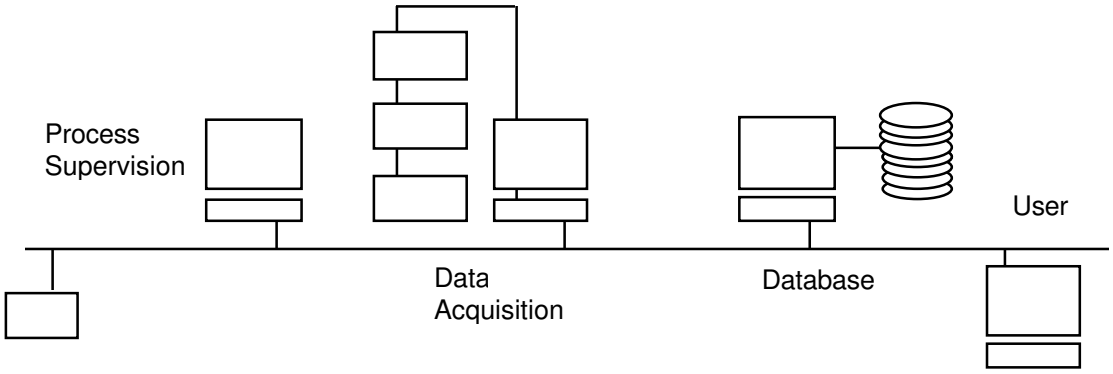
The recording strategies adopted for both the archiver and the transient recorder greatly contribute to reduce the amount of data early in the acquisition process.

The application displays on two screens 12 stripchart recorders, each showing the behaviour of five system variables, in real-time or stored mode. The application allows the entry and edition of configuration parameters for the archiver and transient recorder parameters, as well as the conversion type and coefficients for each input channel. Additionally, it exports the data into ASCII files which are inserted into the database at regular intervals.

IV. THE DATABASE

The database was largely inspired by the experience in LEP and SPS [14, 15] where operations data are regularly stored in a database and are available to specialists for machine studies or diagnosis of unexpected events. In the LHC Test String, data recorded by the acquisition system and stored in the supervision journal files are inserted in the database at regular intervals, usually once per 24-hours around midnight.

The data transferred from the acquisition system comprise both raw and converted values from the archiver and the transient recorder. Additionally, the configuration data which contain conversion information and sensor data are inserted in the database. With this and the raw data, it is possible to reconstruct the conversion in case of doubt, or reconvert data from the raw values if a better calibration is subsequently produced. For the supervision system, however, only the converted data in engineering units are transferred.



In order to reduce the table sizes and hence optimize extraction times, the data for each run are stored in separate tables having the same structure. Each of these tables has five columns; the first two represent the date and time respectively, the third is the identification of the channel and the last two are the raw and the converted values. Since the data for any two channels is almost never recorded at the same instant (see section on the functionality of the data acquisition system), only one set of two columns containing channel data is attached to a time stamp.

Placing data of previous runs in different tables allows us to partially back-up the database on disk, since these tables can be backed up on tape once the run has finished.

The transient data is placed in one table that has 5 columns. The first corresponds to the event that triggered the data acquisition, the second to the number of milliseconds after or before this event. The last 3 columns are identical to the last 3 columns of the archiver tables.

Once the data is in the database, it is available on every desktop at CERN either by using a desktop application on a PC or through a World Wide Web page [16].

V. COST

The supervision application for the CWU, the SFB and the Vacuum of the LHC Test String has cost 15 man•months and 35 k CHF for both the hardware and the software. The process control for the vacuum and

the PLC communications for the whole project is evaluated at four man•months. The SFB process control is a continuing operation since the many structural modifications of the LHC Test String generate modifications in the process control: it can, however, be evaluated at 12 man•months.

The cost of the data acquisition system is better known: it amounts to 270 kCHF after the system upgrade following RUN1.

The database system was constructed as an upgrade of an existing installation and the cost of hardware was 60 kCHF, while 15 man•months have so far been invested for the design, implementation, commissioning and running of the database and associated data extraction tools.

VI. PERFORMANCE

The performance figures are given for RUN1, which started on February 22 1995 and ended on June 12. Many improvements to the different systems have been made during the shutdown following RUN1, but no long term experience is yet available to assess their effectiveness.

On one occasion only during RUN1 the supervision system was down for two hours as a result of an error of manipulation. One programmed stop per week to install requested upgrades was negotiated with the users during the run. However, during the commissioning a continuous assistance was provided by the supervision and process control teams. The process control PLCs exhibited malfunctioning only during the initial tests preceding commissioning; the PLCs were stable during the run and did not visibly contribute to down-time of the LHC Test String. 850 datapoints are read from the field every 10 seconds, 255 data points are archived every minutes yielding, 250 Mbytes of data for RUN1.

The archiver part of the data acquisition system was continuously running throughout the run, except for a weekend when it was inadvertently stopped. Additionally, as for the supervision system, programmed stops were negotiated to install requested system upgrades or bug fixes. This amounted to 5% of the run time.

The transient recorder missed only one trigger over 48 due a wrong configuration file loaded by mistake by an operator.

The database design started very late in September 1994; at the beginning of RUN1 in February 1995 a first version was ready to accept data. No time was available for prototyping and tests with large amounts of data. The data insertion programs interpreting files exported from the data acquisition system were gradually commissioned. After several trials with Oracle® products for data presentation, it was decided to write an Excel® application to extract the data and chart it. The performance, although initially acceptable, started to decline as data increased the sizes of the tables. A consultant was asked to examine the performance of the system and he came up with a number of recommendations which were duly implemented. Typical extraction times obtained today are just above one minute for three signals recorded during one week and averaged every 10 minutes. 6.5 Gbytes of data were inserted in the database during RUN1.

VII. CONCLUSION

The control and supervision systems were the ones we were most familiar with. We benefited from experience gained on similar installations with a comparable amount of PLCs and field parameters. The process for the String Feed Box was by far the most complex with 24 control loops which switch reference variables depending on the operational phase. Despite some initial difficulties with the communications, the supervision benefited from a mature product and has performed reliably since the beginning of RUN1.

The data acquisition system has performed as specified: reliable, in-time and user-friendly. It has been our first experience with turn-key systems specified for, and built by, industry. The project has benefited from a mature technology both for the hardware and the software; ready-made available software components have greatly contributed to the success and low-cost of the project.

The performance of the database was by far the most difficult to achieve and maintain at the level required by the users. Although the problems of such a database were known because of experience with LEP, additional problems were encountered in fields such as transfer of data to the database and extraction times of data. The volume of the database started to increase very rapidly at the beginning of the run; after one and a half months of operation the average number of points recorded per unit interval was halved by carefully tuning the

archiver. This was achieved by adjusting the value of ε for each channel recorded by the archiver which had been set too low.

VIII. ACKNOWLEDGEMENTS

The authors would like to thank the LHC Test String Project Leader, P. Faugeras for his continued support and the confidence he put in them. Because the data acquisition project took the form of a collaboration rather than a commercial deal, the authors would like to acknowledge G. Endendijk and D. Motshagen from INCAA Computers, Apeldoorn, Holland. We would also like to thank our colleagues in the SL and CN Divisions of CERN, S. Santiago, C. Delamare, R. Billan, N. Segura-Chinchilla and I. Reguero for their advice and help on issues related to database design, commissioning and daily operation. Last but not least, our thanks go to the String Team and other users, who by their light-hearted and natural approach to our systems have shown us what they were there for.

IX. REFERENCES

[1] P.Faugeras, Assembly and Commissioning of the LHC Test String, Particle Accelerator Conference PAC95 Dallas, 1-5 May 1995

[2] P.Kraushaar, The Accelerator Systems String Test Program, SSCL Pre-print 333, May 1993

[3] A.Bézaguet, J.Casas-Cubillos, B.Flemsaeter, B.Gaillard-Grenadier, T.Goiffon, H.Guinaudeau, P.Lebrun, M.Marquet, L.Serio, A.Suraci, L.Tavian, R. van Weelderen, The Superfluid Helium Cryogenic System for the LHC Test String: Design, Construction and First Operation, Cryogenics Engineering Conference, Columbus, Ohio, 17-21 July 1995

[4] F.Rodriguez-Mateos, L.Coull, K.Dahlerup-Petersen, D.Hagedorn, G.Krainz, A.McInturff, A.Rijllart, Electrical Performance of an LHC Test String of Magnets Representing a half-cell of the LHC Machine, Magnet Technology Conference, 11-16 June 1995, Tampere, Finland.

[5] B.Angerth, F.Bertinelli, J-C.Brunet, R.Calder, F.Caspers, P.Cruikshank, J-M.Dalin, O.Gröbner, N.Kos, A.Mathewson, A.Poncet, C.Reymermier, F.Ruggiero, T.Scholz, S.Sgobba, E.Wallen, The Large Hadron Collider Vacuum System, Particle Accelerator Conference PAC95 Dallas, 1-5 May 1995

[6] R.Saban, Integrating Industrial and Accelerator Control Systems, Particle Accelerator Conference PAC95 Dallas, 1-5 May 1995

[7] M.Rabany, A Proposal to Move from the LEP Topologial to an LHC Funtional Control System Architecture, this conference.

[8] Technical Specification for the Delivery and Installation of Cooldown and Warm-up Units for Superconducting Magnets, IT-1987/LHC/AT, October 1991.

[9] USData®, Factory Link® Fundamentals, Version 4.4, 1995

[10] Siemens, Communication Processor CP143, Users Manual Volume 1 and Volume 2, 1993

[11] National Instruments, LabView® User Manual, September 1994

[12] Specification for a Data Acquisition System for the LHC Test String, CERN/AT-Group Note 94-02

[13] National Instruments, Instrumentation Reference and Catalogue, Test and Measurement, Process Monitoring and Control, Section 4 on VXIbus and MXIbus Products, 1995

[14] R.Billen, F.Bordry, C.Delamare, E.Hatiangeli, F.Roeber, LEP Accelerator Logging System Using On-Line Database, ICALPECS93, Berlin, November 1993.

[15] R.Billen, E. Hatziangeli, I.Laugier, I.Reguero, N.Segura, Mission Critical Database for SPS Accelerator Measurements, this conference

[16] F.Momal, Using World Wide Web for Control Systems, this conference