22. MAGNET CONTROL SYSTEM

22.1 PRINCIPLES

The Magnet Control System (MCS) is integrated into the CMS Detector Control Syst em (DCS) [22-1]. It is capable of working independently or as part of the overall CMS DC S. It includes four parts:

1. The Sensors and Actuators of the magnet, auxiliaries and closely related infrastr ucture.

2. The Programmable Logic Controllers (PLC�s) including a Test and Development Station (TDS) for development, testing, commissioning and debugging of the process co ntrols.

This process control sub-system is programmed for full automated functioning of t he magnet system and ensures:
- working sequences of the proximity cryogenics, vacuum system, power supply,
- control of heating and gas flow regulation of the current leads,
- transmission of alarms and of all parameters readout.

3. The Magnet Safety System (MSS) which aims, in case of fault, to secure in an enti rely automatic mode the magnet and auxiliaries with hardware equivalent protections of two kinds:
- specific protection like Transition Detection System, current lead faults ...
- standard protections like usual interlock system acting on water flow limit , water leak detection, power supply fault...

Both are combined to trigger appropriate discharge of the magnet and hence elimi nate any risk of damage. This system must provide the highest level of reliability.

One imbedded PLC in parallel allows on-line analysis of the safety parameters and offers redundancy in securing the magnet as well as more intelligent exploitation tools.

All necessary parameters and alarms related to this system are transmitted in real time (a few seconds) to MCS to enable supervision and fault analysis.

4. The Magnet Supervisor (XMS) [22-2] which is a component of the CMS DCS and, as such, provides the user with all functionalities of a DCS component, includes:
- supervision and control facilities,
- operator�s assistance and diagnostic facilities.

The user will be able to use a DCS operator desktop in the experiment control roo m, or in the service cavern or from remote locations. Different types of users have to be considered and will be described in parag. 22.3.

The conceptual control system structure is shown in Fig. 22.1. Fieldbus technology will be used at the level of the PLC�s and at the level of the sensors and actuators. Provi sion will be made to have the possibility to revert to direct cabling of the sensors and act uators to the PLC's if magnetic field or radiation effects happen to cause disturbance.

The partition of MCS in four parts can lead to the same partitioning in terms of pro curement. Testing, installation and commissioning are independent of the availability of XMS.

PLC's with TDS can be treated in an industrial turn-key system approach, whereas XMS is produced as a DCS component.

MSS is an autonomous system using possibly custom design packages whose para meters are input to the PLC's.

Independent commissioning of sub systems is ensured. Local diagnostics and fault finding at commissioning as well as flexibility is provided with the help of TDS.

MCS control system is required to interface with other systems in CMS:

- Top level MCS experiment through DCS / CMS operations in CMS control room.
- MCS refrigeration plant (external cryogenics) and Central CRYO control room.
- LHC Machine operations / LHC control room.
- DEAS Detector and Experimental Area Safety System.
- Technical services (Technical Control Room TCR).
- Infrastructure and general services (relevant vital information will be acqu ired directly at the Infrastructure PLC level).
- Power Converter Service.
- Maintenance call and help service.

Interface requirements are partially detailed in 22.5 and will need special care.

Every effort will be made to standardise, as far as possible, the different Magnet Pr ocess Control Systems of the LHC experiments. This option presents obviously different advantages, but the most evident are those of minimising the number of staff having the same level of competence on the field, and reduce the storage of spare parts for the same level of reliability.

Wherever possible, one will try to take advantage from the choices adopted for the LHC machine, because CERN, as host laboratory, will have the heavy charge of satisfying reliable and inexpensive running of the LHC experimental complex.

Cryogenics is one of the most evident examples but other common fields are curre ntly being investigated.

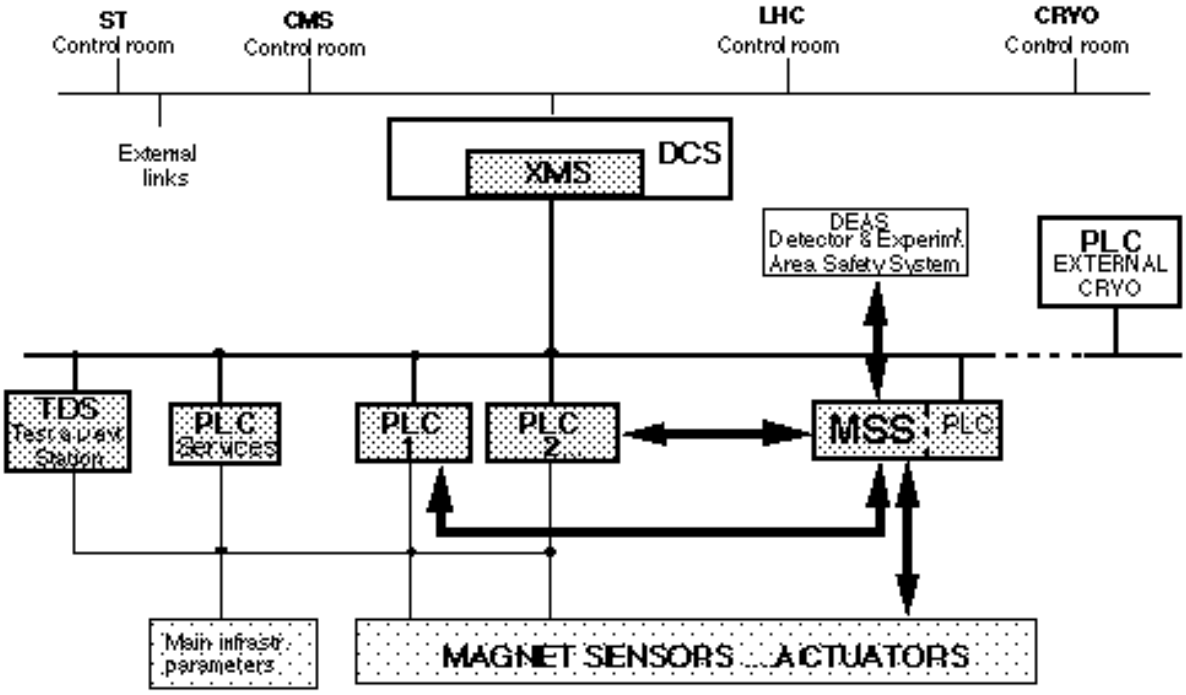

Fig. 22.1: Conceptual Control System Structure.

22.2 INSTRUMENTATION

There are many ways for connecting the sensors and actuators to the control systems. We have chosen to connect the sensors, actuators and the PLC's on the same fieldbus, a solution which offers several advantages; if this choice is impossible due to problems of radiation or magnetic field, we have the possibility to revert to hardwired lines. The design of the control system is detailed in Chapt. 22.3. For the instrumentation, the following possibilities are under study:

- connect all sensors to remote input-output modules,
- use smart sensors and actuators (as defined hereafter).

Each of these two possibilities allows to:

- minimise the number of cables between the magnet installation and the control system,
- transmit noise free data to the PLC's,
- adopt an advanced technology,
- optimise the maintenance.

The remote I/O systems are well developed in industry and are commercially available. The use of remote modules is now well-tested. These modules transmit values of all sensors and receive commands for actuators as numeric data through the fieldbus. They allow the following functionalities:

- diagnostics,
- wiring tests,
- power supply module monitoring,
- failure position,
- programmable filtering,

- status memory.

Nevertheless, the remote modules transmit only the values of the sensors. Any error in the measurement (noisy signal, shift or other deviation between real value and transmitted value) produces effects in the control system. However the use of smart sensors and actuators allows to minimise such effect. The smart sensors have local processing capability and a fieldbus port. This technology has the same advantage as the remote I/O module technology; moreover it ensures the following functionalities:

- transmit confirmed information on the fieldbus (e.g. the measured pressure value is linearised and temperature compensated),
- automatic control of the sensor internal processing,
- large range of measurement which may help to reduce the number of spare sensors.

The physical parameter measurement on the magnet installation are for the cryogenic part:

- flows,
- pressures,
- levels,
- temperatures,
- movement of cold mass.

For the magnet safety, the physical parameters are:

- currents,
- voltages,
- temperatures,
- pressures,
- levels.

These parameters are transmitted to the MSS as detailed in Chapt. 22.4.

The actuators are mainly analogue valves, flow valves and vacuum pumps. For the actuators, the same alternative solutions as for the sensor are under study, (i.e. remote module and smart actuators). The smart actuators are presently only in the prototype development stage. Therefore, the use of I/O modules for actuators is safer at the present time.

To resume, at present the following instrumentation is considered:

- sensors: smart sensors or sensors with remote modules on fieldbus,
- actuators: remote I/O modules (smart actuators are only in prototype state),
- safety signals to HL / MSS: electronic treatment in cavern and direct transmission to HL in MSS,
- safety signals to PLC / MSS: electronic treatment in cavern and transmission to be defined.

22.3 CONTROL SYSTEM

According to Fig. 22.2, the control/command design is composed of several PLC's.

Each of them controls an independent subsystem. This division conforms the installatio n functionalities and its advantages are:

- easy testing and debugging; each subsystem can be tested alone without w aiting for the other subsystems to be operational,
- improvement of the maintainability and availability of the experiment,
- independent development of the PLC software.

Each subsystem ensures one or many functionalities in the experiment as indicate d in the table below:

Table 22.1
Subsystem functionality.

Subsystem	Functionality
Cryogenics	- Cool down - Control loop for the exploitation parameters - Warm up
Vacuum	- Ensure a good vacuum
Alignment	- Alignment between the magnet and iron mass
Current leads	- Control loops: flows and temperatures at top of CL
Magnet Safety System (MSS)	- Quench detection - Detection of current lead fault - Communication with XMS
Power Supply	- Power supply parameters control

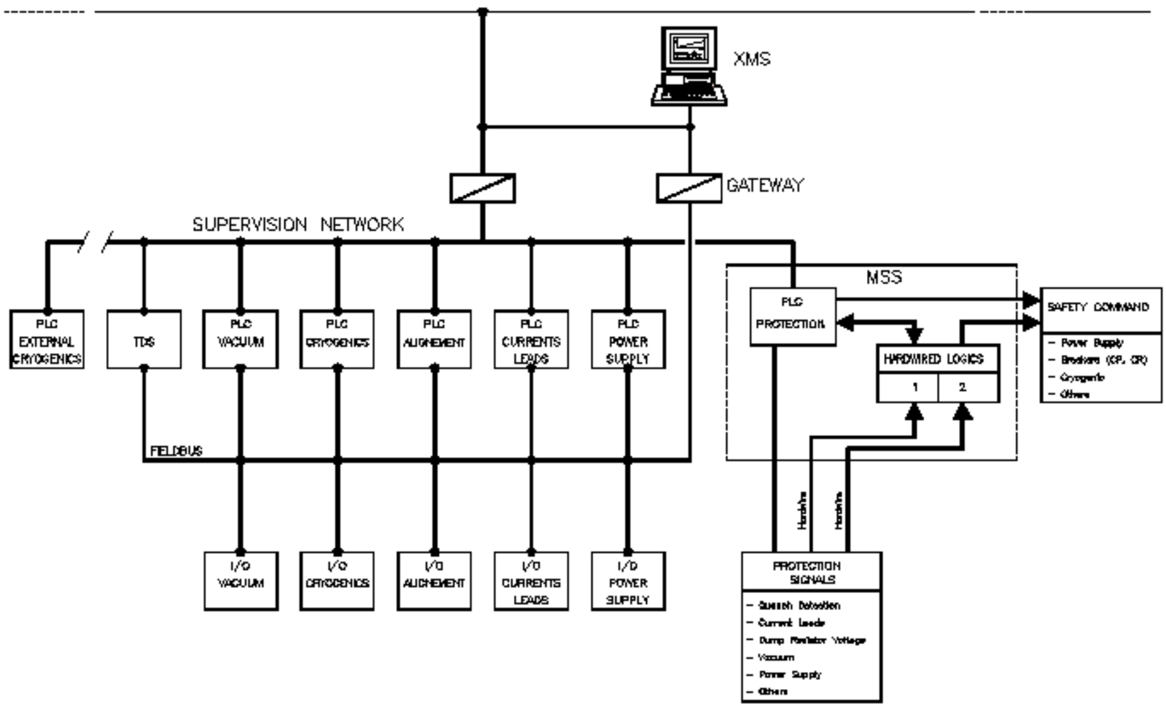

Fig. 22.2: Control system architecture.

The whole of the control/command is monitored by the XMS through two gateways if these are requested by the communication protocols. Nevertheless, two connection lines are necessary:

- the first one with the fieldbus for on-line monitoring of all control parameters,
- the second one on the supervisor network for diagnostics. The latter connection enables the understanding of the process, to ensure optimised maintenance, to monitor all states in the running mode.

This design is built with four kinds of users in mind:

- the operator: during running, he is the first user interested by the experiment status,
- the maintenance leader: in case of failure in the process, he can analyse the different process states, effect a temporary remedy or ask the maintenance team for an emergency intervention,
- the experts: in the debugging phase, they analyse all the problems and they need data close to the real process,
- the control system designers: will work with the experts in the debugging phase; they need data on the internal state of the PLC's, fieldbus, remote modules ....

22.3.1 The PLC's

The PLC's are programmable electronic systems with microprocessors. They process discrete, analogue or numeric signals in real-time.

They have the following advantages:

- processing time adapted to the cryogenic process,
- processing of analogue parameters,
- resistance to industrial environments,
- longer lifetime.

The PLC's allow the following processing:

- manage the operation of the installation,
- ensure control loop,
- ensure subsystem safety,
- help to run diagnostics.

The design of each PLC will be studied later taking into account the availability constraints.

22.3.2 The fieldbus

The fieldbus is the mean of communication between:

- the sensors-actuators and the PLC's,
- the PLC's themselves,
- the TDS and PLC's,
- XMS and the sensors/actuators.

The fieldbus protocol allows all PLC's to access all sensor values. This possibility simplifies the cabling in the case that several PLC's need to access the same sensor.

The choice of the fieldbus is not yet made. Nevertheless, the fieldbus will conform to the recommendations of the "Working Group on Fieldbuses" of June 26, 1996.

The parameters for the fieldbus choice are:
- critical time,
- transmission of data with determinist cycle,
- capacity for transmission of analogue data,
- total length,
- transmission speed,
- design simplicity.

If the fieldbus technologies present any problem with radiation or magnetic field, the connection design allows to transmit parameters with hardwired lines.

22.3.3 The supervisor network

The choice of the supervisor network depends of the communication protocol of the XMS. Nevertheless, the data in this network is intended for XMS. It is used for diagnostics, to understand the installation functioning, to monitor the installation state and maintenance. This network is not a critical element in the architecture because it is not essential for system operation.

22.4 MAGNET PROTECTION (MSS)

22.4.1 Principles

The CMS experiment must run for several months each year without interruption. The experiment monitoring will be done from a control room located in a surface building.

The magnet safety is ensured by two independent systems, using different technologies:
- Hardwired Logic (HL).
- PLC's.

The MSS design is shown in Fig. 22.3.

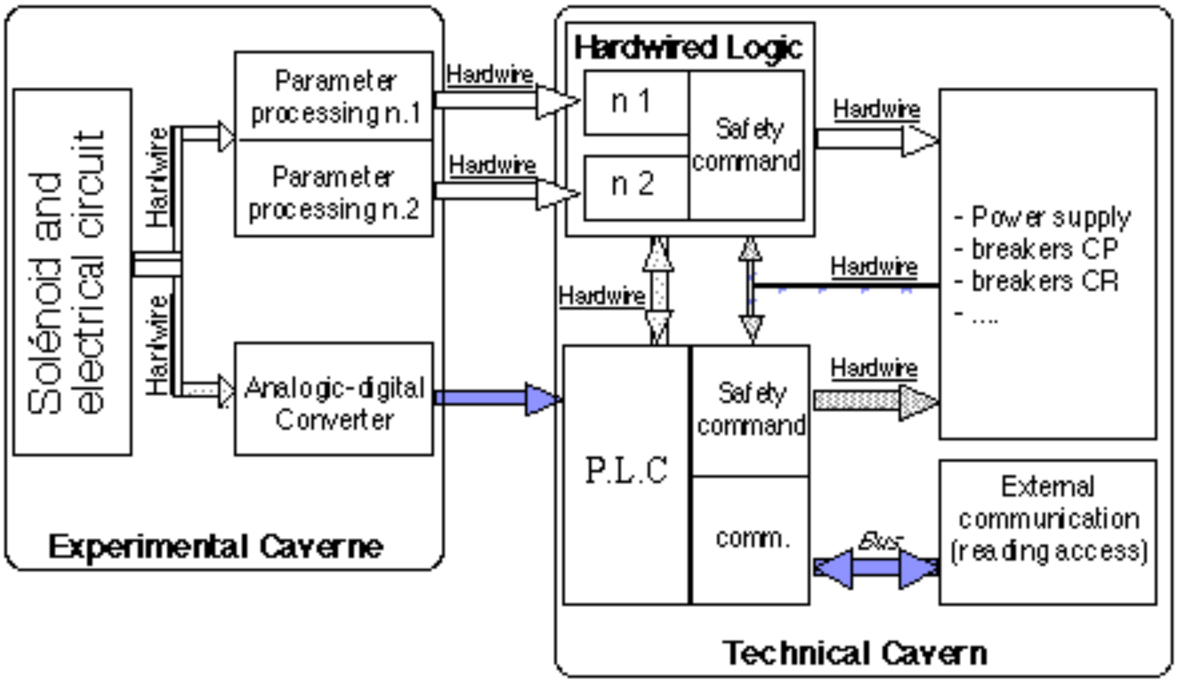

Fig. 22.3: Magnet Safety System Design.

22.4.2 Protection actions

The main purpose of the protection is to ensure CMS solenoid safety by dischargin g the stored energy in one of two modes:

- Slow Dump (SD),
- Fast Dump (FD).

The protection principles are detailed in Chapt. 20.

The Slow Dump is the regular mode of decreasing the current on operators request and the safety mode of discharging the solenoid in the event of minor faults. It is done b y closing the breakers CR1 & CR2 and opening the breakers CP1 & CP2 (Fig. 20.1).

The Fast Dump is an emergency mode triggered by major faults giving a rapid disc harge of the solenoid. It is done by opening the breakers CR1 & CR2 and opening the bre akers CP1 & CP2.

22.4.3 Safety system reliability

The safety parameters are analysed on-line. Signal thresholds trigger appropriate safety commands (SD, FD, warning ...).

The two hardwired logic systems ensure a high dependability due to their structur al and logical simplicities.

The PLC, along with its role for data acquisition, duplicates the same safety functio ns as the hardwired logics HL, but it works with signal thresholds set to lower values tha n those of the HL.

The association of HL with PLC's gives users several exploitation possibilities such as:

- memorisation of parameters in the pre- and post- quench period,
- memorisation of the parameters in normal continuous operation,
- on-line monitoring of the various parameters,
- monitoring the parameter shifts with time,
- automatic change of threshold related to parameter shift,
- ease of diagnostics in case of installation failure ...

22.4.4 Magnet Safety Interlocks

The safety signal treatment is ensured by two independent hardwired logic channels and a PLC channel. All safety sensors are doubled or perhaps tripled.

The hardwired logic parameters are processed by electronics located near the sensors in the experimental cavern, then transmitted to the MSS in the technical cavern.

For the PLC, the parameter signals will be transmitted between both caverns in a mode yet to be defined.

The magnet safety interlock scheme is shown in Fig. 22.4.

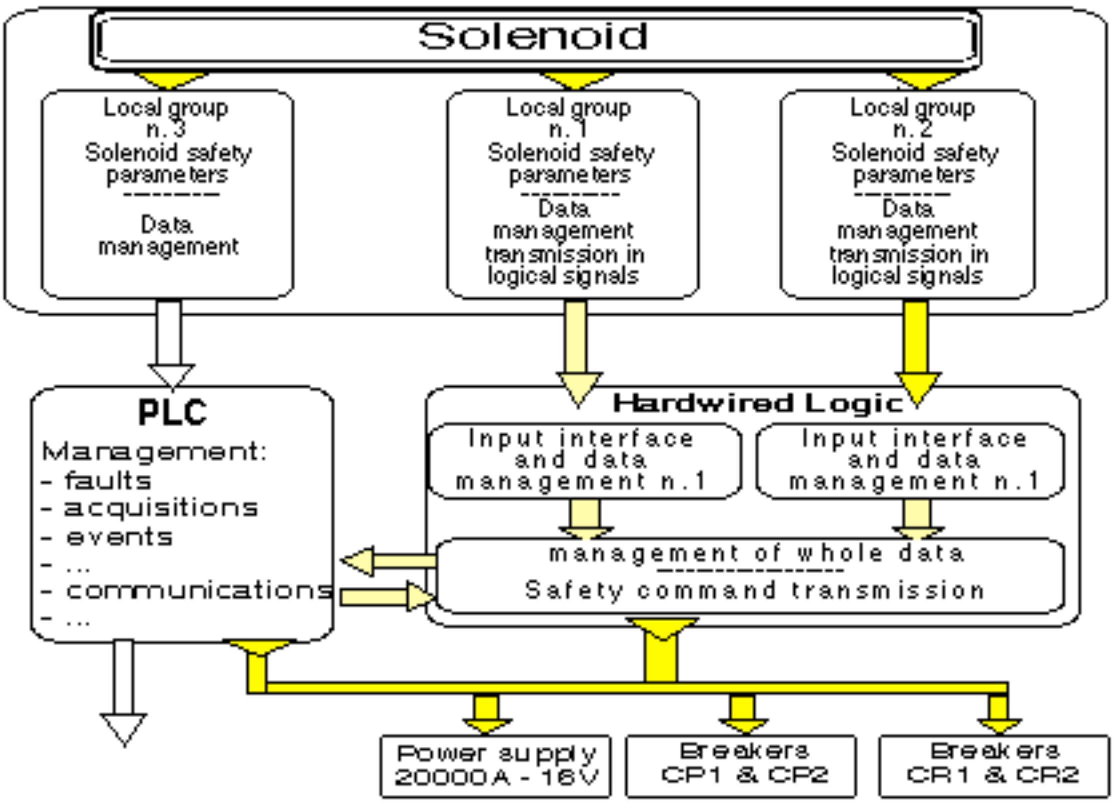

Fig. 22.4: Magnet safety interlocks.

22.5 INTERFACES

A conceptual diagram is shown in Fig. 22.5 summarising the list of interfaces between the systems given in parag. 22.1.

Since XMS is a DCS component, interfacing through DCS is provided with all components of DCS and all control systems interfaced to it. This is achieved via experiment and/or CERN networks.

In some cases, direct links are necessary at the PLC fieldbus level or at the signal level for reliability and/or safety reasons. This is in particular the case for the links with the refrigeration plant which will have to exist at all levels:

- DCS level for general status exchange,
- PLC's level via fieldbus at process control level (warming up or cool down sequences for example in which the external cryogenics takes full control over the proximity cryogenics and the magnet),
- limited direct hardware links for the exchange of vital signals (needed for example in case of fast discharge).

Interfacing through fieldbus requires that External Cryogenic Control System and MCS use compatible PLC and fieldbus systems. This will be achieved by selecting the relevant equipment of MCS within the range of products acceptable to the External Cryogenic Control System.

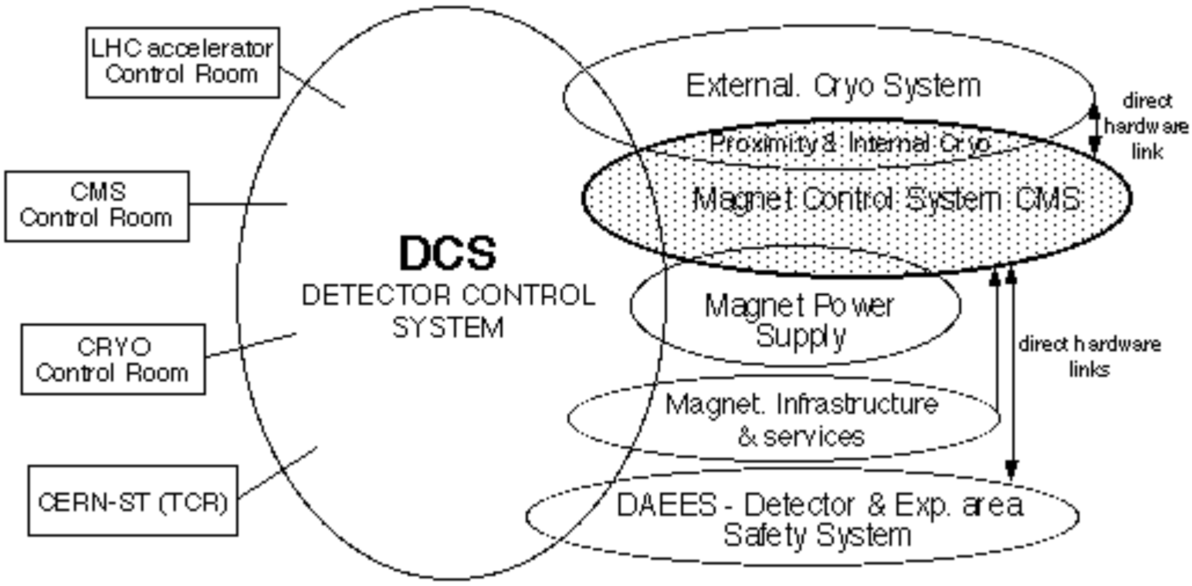

Fig. 22.5: Conceptual Interface Diagram.