CERN/PS 98-007 (CO)
24.03.98

Realisation of the D067 Project : Implementation of the CPS Accelerator Complex Control System

Christian Serre

Abstract.

The aim of this document is to give a general overview of the implementation of the CPS Accelerator Complex Control System as a part of the D067 project. Within the framework of this project, the main reasons for the collaboration between PS and SL Divisions, which allowed the common design of the accelerator control system, will be reiterated. A description of the basic concepts and constraints, main parts, operator interface and applications, exploitation and future evolution of the CPS realisation of this common accelerator control system is given.

A chronological list of references (mainly of conference presentations) completes the report.

1. History of the Project.

The aim of this document is to give a general overview of the implementation of the CPS Accelerator Complex Control System as a part of the D067 project. Within the framework of this project, the main reasons for the collaboration between PS and SL Divisions, which allowed the common design of the accelerator control system, will be recalled. A description of the basic concepts and constraints, main parts, operator interface and applications, exploitation and future evolution of the CPS realisation of this common accelerator control system is given. In the Appendixes the main assessment of the CPS part of the project is detailed. A chronological list of references (mainly of conference presentations) completes the report.

At the end of the 1980s, the consolidation of the PS and SL accelerator control systems had become necessary and urgent. The increasing intensity and complexity of the particle beams to be produced in a clean and reproducible way by the PS and SL machines required a more reliable system for controlling parameters and acquiring beam instrumentation data. The operational requests for more powerful real time control and treatment of the acquired data (as close as possible to the hardware) were no longer possible with control system components (hardware and software) developed in the late 1970s.

It was felt that one should profit from this need for a consolidation to aim at a real convergence of CERN's accelerator control system [1-6]. The rejuvenation process, known as D067 project, was a splendid opportunity to let PS and SL Divisions converge towards the same technical solutions. Since the beginning of 1990, the collaboration between PS and SL control groups was reinforced to create a common design, also called the "standard model". The design and the resulting proposals were presented to a wide selection of the staff of the PS and SL Divisions (including control staff of AT and ST Divisions), then to the CERN Directorate and were agreed at the beginning of 1991 [7].

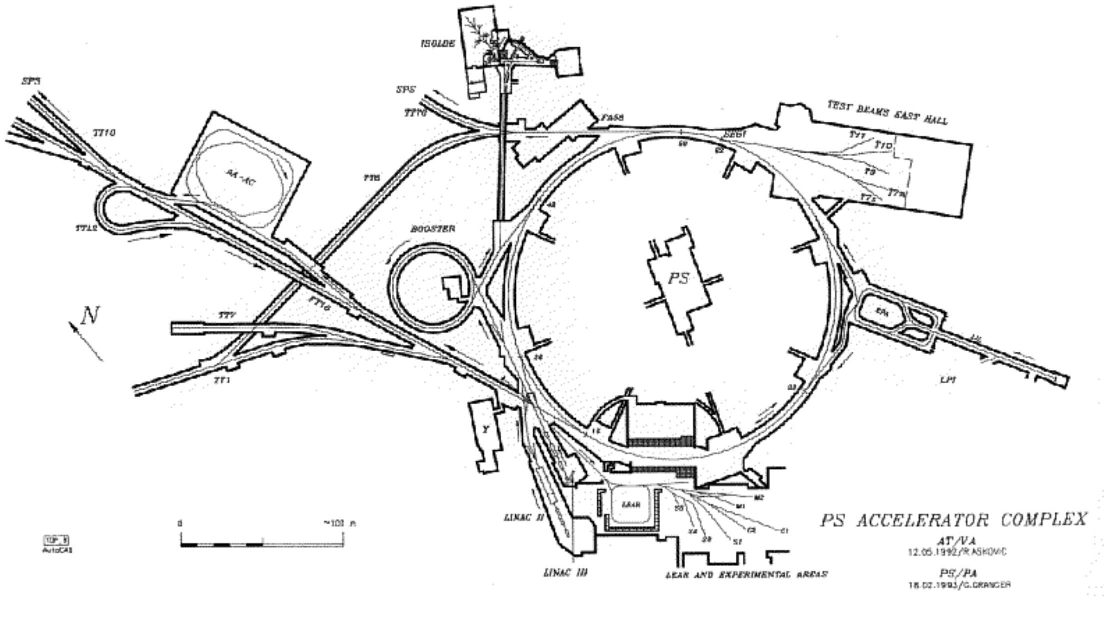

Fig.1 The CPS Accelerator Complex in 1996.

The information given below is mainly for the CPS complex [Fig.1], even if several sub systems or equipment were realised by common PS and SL teams. The main ideas on which the rejuvenation of the CPS control system implementation was established are:

- replacement of the obsolete NORD 16 bit mini-computers (poor reliability, both hardware and software, expensive maintenance contracts, difficulties to correctly maintain the components), of the CAMAC embedded microprocessors and of the control interfaces designed mainly in 77/78,
- integration of basic Control Model and Architecture and components designed for the CERN Accelerators Common Control System,
- realisation in several annual slices in order not to perturb the agreed schedules for the particle production and machine shut-downs.

2. Budget and Resources.

Budget :
The D067 budget was established and presented to the Directorate as a whole for both divisions. The allocation between the two systems was discussed by the joint project leaders and the Accelerator Department head every year. On the PS Division side, the budget included the general control infrastructure, the workstations, the servers, the network, and the front-end processors. It was decided that the equipment control interface would be added to the control budget: power converters, RF systems, kickers (KSU), mechanical movements, vacuum, as well as the digitised signal observation system (nAos). The only exception was the “specific” interface of the Instrumentation, for which a specification could not be given because of lack of an executive structure dedicated to the beam instrumentation in the PS Division at the time of D067 budget discussion (no PS/BD group in 1990).

Resources :
The design of the Common Control System for the CERN Accelerators was a joint effort of the PS and SL Divisions. During 1990 and part of 1991 the definition of the main parts of the system was completed by different working groups constituted by PS and SL staff [7,9]:

- The first working group designed the common control system architecture, the front end processing and discussed the network characteristics, the local control facilities and the interface between the controls and equipment groups.
- The second working group defined a common approach to the application software needed to run the accelerators, discussed the programming environment and the possible software tools and studied the future layout of the work place in the control rooms.
- Other groups, linked with the two previous ones, worked on specific subjects such as the Equipment Control Protocol, the Man Machine Interface (MMI), the Timing and Synchronisation problems.

Inside the PS Division, the PS/CO ensured the co-ordination of the project, but the realisation was the common effort of all the PS groups during the years 90 to 97: CO, OP, BD, PO, HI, RF, PA, LP groups participated both on hardware and software realisation. The vacuum control was completely took on by the AT-VA group. At the beginning of the project, contracts with external firms were employed (first step, LPI); but a later reduction in the budget imposed the use of other less expensive solutions such as students, fellows, VSNA and associates. On the software side the CO group was in charge of the realisation of the Drivers, the Equipment Modules, the Real Time tasks, the general software for the infrastructure and the generic application programs and interaction environment from workstations (Console Manager with generic MMI applications). The specifications and the realisation of the operational application programs for workstations were delegated to the OP group. The specific part of the software was the work of the equipment and instrumentation groups, like BD, PO, PA, RF and AT-VA.

3. CPS Complex Implementation: Basic Concepts and Constraints

3.1 Basic concepts

The "standard" model used in the CPS complex is the image of the common architecture of the CERN Accelerator control system [20]; it consists mainly of three different layers [Fig.2]:

- control room layer with workstations and central servers; the connection to this layer is done only through Ethernet.
- front end real time computing layer distributed around machines, based on VME crates with embedded processors called DSC (Device Stub Controller)
- equipment control layer with ECA (Equipment Control Assembly) crates which form part of the equipment and are controlled by the DSC through field buses.

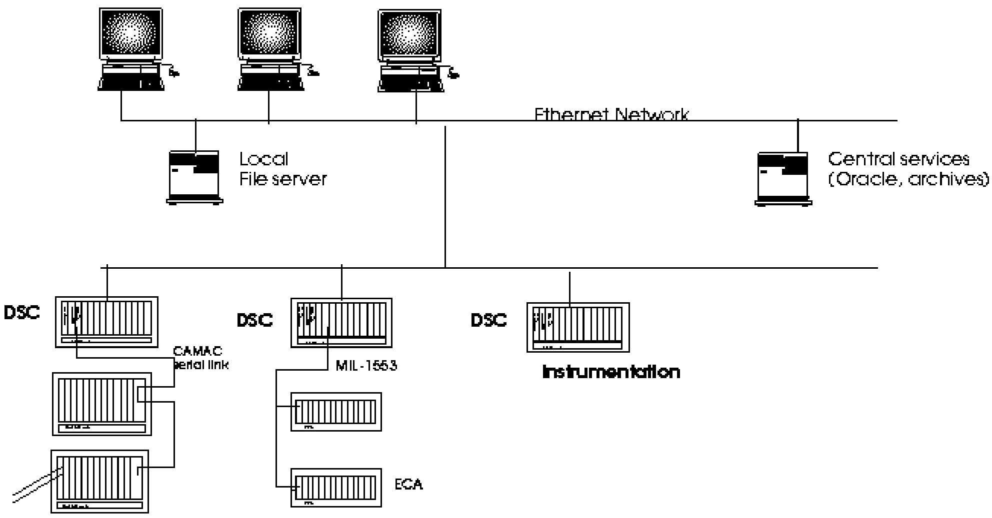

Fig.2 The basic Architecture of the CPS Control System

The first and second layer processors run UNIX-like systems; they communicate on an Ethernet based network. The second and third layers are linked through different field buses (serial CAMAC, MIL 1553, RS432, GPIB). The network between the first two layers is structured in central and regional LANs [Fig.3]. This split was made to provide enough robustness, and autonomy in the event of local disturbances on the network. The central LAN includes the operator interface workstations and their servers together with the Central Services and the Data Base server (On line DBMS ORACLE shared by PS and SL control systems). The different regional sub networks incorporate the DSCs, the local workstations and the server belonging to one machine. The control sub networks are separated from the development (workstations and DSCs) network, the office PCs and the CERN Public Network by a filtering router (CISCO). On this separate segment, the development environment (workstations and DSCs) is kept as identical as possible with the control environment.

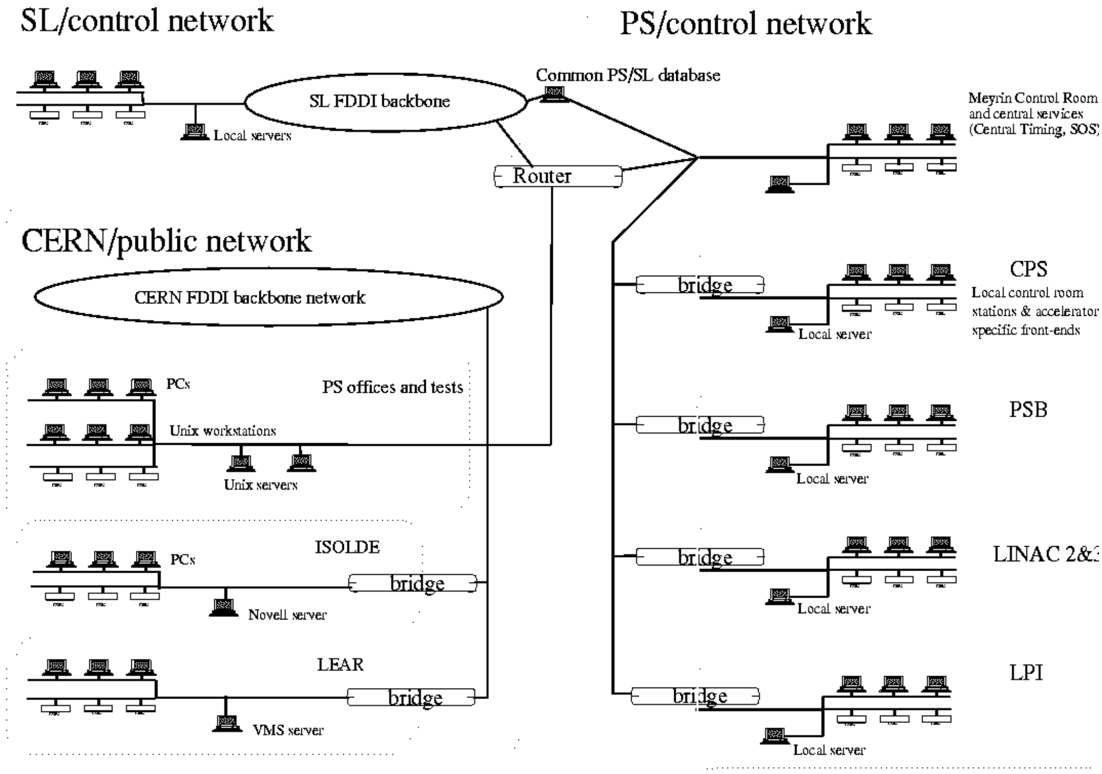

Fig.3 The CPS Complex Control Network in 1996
and its connections to the outside world.

This "standard model" was adapted to the existing CPS hardware investment (CAMAC crates and modules plus equipment interfaces), carried out since 1980. The existing software investment was preserved, keeping the existing equipment access structure with the EM (Equipment Modules), the Real Time (RT) tasks for the CPS Pulse to Pulse Modulation (PPM), and re-using the modules already written in "C". The “Control Protocol” was defined as a standard access and as a boundary to the "specific" parts of the software. It was set-up for the Instrumentation and for every new interface introduced in the system (RF cavities, vacuum, power converters, mechanical movements). The NODAL interpreter was ported on the DSC platforms and on the workstations; an emulation of the old console tools was provided as a temporary solution for a fast porting of some application programs.

3.2 CPS Implementation schedule.

The CPS control system rejuvenation was a six years project implemented as a series of annual slices. Each slice was put in operation during the annual shutdown, at the beginning of the year. The preparation of the slice started the year before, including milestones all along the year, with a very important session just before the stop of the machines, at the end of the year. The rejuvenation of the control system of the CPS complex originated in 1991; initially foreseen to last five years (up to 1995/1996), it was at the end divided into six steps :

- 1990/1992 : the LPI complex (LEP Pre Injector: Electron and Positron linacs, Electron+Positron Accumulator) control system was completed at the start-up of 1992,
- 1991/1994 : the linac2 (source of the protons) control system was put in operation at the beginning of 1993 (whilst the second part of this step, the linac3 (Lead Linac) was done during 1993/1994);
- 1993/1994 : the third step, the PS Booster (PSB) machine control was operational at the end of the first trimester of 1994
- 1994/1995 : CPS Injection and Acceleration, was done at the start-up of 1995

- 1995/1996 : CPS Ejection and Beam Transfer (TT), the second part of the PS machine, was completed during the shut down of 1996
- 1996/1997 : the General Consolidation step, including general synchronisation and timing, plus different items delayed along the project, closed the D067 Rejuvenation Project for the CPS complex in March 1997.

3.3 External Constraints and Implications.

The external constraints, technological and managerial, took a significant weight during the life of the project. The initial schedule evolved all along the life of the project, following the change of the priorities given to the different operations, the availability of the manpower and also the technological evolution. The initial strategy had to be reviewed annually and the final decision was taken at the divisional level.

One of the first external constraints was both a managerial and a technological one. The choice of the UNIX operating system was enforced for the accelerator control system by a managerial decision. A Real Time Kernel, UNIX-like, had to be found at the equipment control level which was running on DSC, both VME crates and PC, instead of the OS9 operating system which was the initial choice for a question of availability, CERN general support and knowledge. The operating system selected for both PS and SL systems was the LynxOS which became ready for use on both sets of hardware during 1991; that was in the middle of the first step preparation, at the time a certain number of basic software was already written. This choice of LynxOS brought with it coherence inside the network, amelioration of software development and testing conditions, and increased collaboration between the accelerator divisions. But it was a source of disturbances for the operational start-up of the first step in 1992 (change of priorities, extra work, operating system courses and local support).

A typical example of external managerial constraints was the "priority" given to the different projects and especially the modification of these priorities following the Physics program. For the CPS control system rejuvenation, the best example was the request to integrate the linac3 (also called lead linac) control system during the year 1993, to allow the commissioning foreseen for 1993 and 1994. To fulfil this request it was necessary to swap the different steps and to provide the linac2 (also called proton linac) with the new version of control system during the year 1992 as a second step of rejuvenation, when at the same time the system of the linac3 was prepared. This change had two main drawbacks: first, no NORD computer could be suppressed during the linacs step, second, the project was extended by one year with a reshuffling of the schedule. At about the same time, the decision was taken to stop the antiproton operation for LEAR in 1996, so the AAC+LEAR step was suppressed.

These strategic decisions resulted in a continuous adaptation of the yearly steps for many reasons :

- connection between the consecutive steps to provide the operation crew of the machines with a coherent ensemble amongst the controls already rejuvenated and the ones still on the "old" control system.
- integration of new managerial priorities, taking advantage of these dictated tasks to make the standard solutions acceptable for every one.
- assimilation of the technological evolution for the software as well as the hardware.
- division of one step into a certain number of subsystems, to handle correctly the amount of work.
- adaptation of the yearly budget and resource allocations to the different tasks envisaged inside the step, and adjustment of the total amount of money to a new budget profile along the years.

These external constraints led to different repercussions. If the technological developments involved an updating, done during the yearly shut down of the machines, the change of priorities between the different projects resulted in a shortage of manpower, which was dispatched on other pre-eminent assignments, and as a consequence a re-shuffling of the general implementation. The cuts in the yearly budget allocations made it impossible to delegate some particular tasks to external software providers and introduced a delay in the integration of new systems and the non rejuvenation of existing obsolete equipment interfaces.

4. Main parts of the CPS Control System.

4.1 Technologies used

The “standard model” of the architecture is based on well established world-wide industrial standards for control networks, communication protocols, equipment, operating systems and man machine interface. This architecture profits from and enforces the use of Open-System products supported by many manufacturers and consortiums which enables us to be as independent as possible from a given manufacturer.

The communication between the control room and the front end processors is based on an Ethernet network running TCP/IP composed of segments linked together through bridges. As said before (chap. 3.1) the control network is separated from the general network by a router box. A Remote Procedure Call (RPC) mechanism is used to call services located in remote computers. TELNET, FTP and NFS distributed file system are also used in the control network. The DSCs are diskless machines, the workstation are virtually diskless, for reliability reasons, efficient file and data management and for easy system operation procedures (like backup).

4.2 Interaction

In the CPS control system, the implementation started with Digital DEC5000 workstations and servers running ULTRIX (1990-1994); in 1995 this was switched towards the IBM RISC/6000 workstations and servers running the UNIX version AIX because the new DEC product line (ALPHA) was not fully compatible with the previous one (MIPS based) (see chap. 7.1). Thanks to these powerful workstations, it was possible to provide the operators with a reliable and user-friendly interface to the accelerators; they run commercial software packages (X-Windows, MOTIF) with suitable commercial tool kits to construct the user interface. The user interface is directed through a console manager and a set of generic programs. (see chap. 5). The operator desk manager (called “Console Manager”) offers selection by way of menus opening a certain number of "widgets" allowing the observation of sets of operational parameters (WSET), the control of these selected parameter (Knobs), the display of instrumentation data and the presentation of the faulty equipments which are surveyed regularly (Alarms). The console manager provides the operator with the “virtual accelerator” view and fully controls the global environment of this virtual machine.

The generic and specific programs interact with the accelerator parameters via an equipment access layer which hides the network topology of the control system from the programs. Two main functions are provided through this equipment access layer :

- a command response protocol, with single/multiple equipment, single action, single/multiple data transaction to the Equipment Modules (EM). This function gives to the application the illusion that the control system is completely based into the user workstation.
- a data subscription mechanism, from multiple equipment (in DSCs) to the application. It acquires locally the data on operational condition (PPM : Pulse to Pulse Modulation), and then the data flow is purely driven by the remote processes [60].

The equipment access layer also supports a gateway to data stored in ORACLE DBMS. In addition to the control values distributed among the DSC, operators are provided with reference values and archives stored in this data base. This uniform equipment access layer gives an easy way to the application programs for building and updating displays. Standard frames were developed to facilitate the production of applications. A fast access using the DBM UNIX facility allows reading control configuration information through redundant on line RT data bases (see chap. 4.5).

A faithful user-oriented tool is the CERN NODAL interpreter language which was widely applied in the accelerator control programming. The workstation version includes the equipment access and most of the facilities which were supported on the previous NORD based consoles (TP, TB, Knobs, Video displays) are emulated via compatible functions and environment [24]. This was used at the beginning of the project to allow a simplification of the work in porting directly the "old" NODAL programs from the console to the workstation.

A controlled bridge between the CPS control system and the PC office network (Novell based and known as the "Passerelle") provides an access from the office and control room PCs, through the Microsoft tool set, to the accelerator parameters for machine studies, equipment or program prototyping and report preparation [17,18].

4.3 Front End Computing

4.3.1 DSC (Device Stub Controller)

The equipment control layer is centred on the Device Stub Controllers (DSC). In the CPS control system only VME crates embedded processors (presently M68030 or M68040) are used; they replace both the NORD front end mini computers and the CAMAC embedded microprocessors (TMS9900 and M68000) [11]. A diskless real time, UNIX like and POSIX compliant operating system runs in these DSC: LynxOS. It was chosen because it guaranties a predictable response time to external events. The main functions of these DSC are:

- to isolate the upper layer from the real time constraints and to manage the dynamic equipment data, according to the Pulse to Pulse Modulation (PPM) requested,
- to provide a uniform interface to the equipment as seen from the workstation through the equipment access layer,
- to act as a master and data concentrator for distributed equipment, interfaced via field buses (serial CAMAC, MIL1553, GPIB, X25),
- to afford specific control and acquisition for equipment like beam instrumentation which needs intensive data processing using a specific equipment software.

The overall structure for equipment access (Equipment Module : EM) remains unchanged. This software layer, formerly located in the NORD front end and in CAMAC embedded micros, was ported to the DSC processors. The EM and their control data (local data table) use the POSIX shared memory segment, and the code of these programs call libraries for data accesses. The same interface library is used by real time tasks for the Pulse to Pulse Modulation (PPM) data handling.

To produce configuration start-up files for all these DSC microprocessors, with the correct drivers, programs and parameters in each of them, the Configuration files were generated automatically from the description of the control system managed by the ORACLE DBMS. The generation process detects inconsistencies and incomplete information[33].

4.3.2 Master Timing Generator (MTG) and Timing Systems.

Timing systems and Pulse to Pulse Modulation (PPM) were renewed [27]. They use a common broadcast bus for the two types of information: coarse timing events (1 ms. clock) and PPM telegram. This bus and both associated hardware and software were developed in close collaboration with the SL Division, opening a way for a common timing system for CERN accelerator complex. A general timing module, the TG8 VME module, is widely used in completely redesigned timing systems [16].

These TG8 modules are used in conjunction with the Master Timing Generator (MTG) which drives the sequence of the different beams generated in the CPS super-cycles [53,59]. The super-cycles are defined as sequences of different kinds of beams, across the accelerator cascade, produced repetitively. The super-cycle is pre-programmed by means of an editor through which the precise requirements of the physics program can be described. The MTG calculates in real-time how each beam will be manufactured according to the defined program and some external conditions, and sends telegrams describing what must be done to each accelerator [36]. This information is encoded and distributed around the accelerator with coarse timing events related to the accelerator process. Around the accelerator complex dedicated VME-standard TG8 modules receive the MTG information, and generate timing pulse outputs. To complete the system, a large number of intervallometers (TSM : Timing Surveillance Module) are used to monitor the timing across the entire accelerator network.

4.4 Equipment Control.

The Equipment Control Assemblies (ECA) control crates of the third layer are connected to the DSC via field buses. Since no predominant standard existed, a certain variety of solutions, both for the ECA and for the field buses, were accepted. In 1990, in the CERN accelerator Control Systems, three field buses were used to a large extent : the MIL 1553 field bus, the GPIB, and the serial CAMAC. At the PS complex, the CAMAC serial highway crates were controlled directly by a VME module in the DSC [12]. Due to the large existing investment in the associated interface equipment, these three field buses were supported.

A control protocol has been implemented on a large scale for equipment belonging to different families [15,25]; these sets of equipment are beam instrumentation (beam transformer, pickup, Q-Measurement, wire beam scanner), power converters, RF systems, vacuum systems, control of mechanical movements. This protocol is introduced between the Equipment Module (EM) Property codes, or the associated real time task, and the specific equipment software/firmware. The main advantages of the operational control protocol are to define a clear separation of responsibilities between the standard and the specific software, to give the specialist the possibility to solve his specific problems in the most suitable way and finally to facilitate and simplify the maintenance of the systems [35]. The control protocol front end (specific processing) is implemented either in the DSC (with a pure local communication) or in the ECA (with communication across the field bus).

It is known that the best results for the control of a given piece of equipment are obtained when the equipment group is totally responsible for its implementation. So, it was proposed to use this general operational control protocol which leaves the equipment people dealing with all the intricacies of equipment, whilst the control groups take care of the operational requests for this equipment as well as of the communication with the specific part. With this scenario, the operation people define a frame for a given equipment interaction, the specialist realises the specific, local software in the most efficient way for each device, and the control group provides a uniform software interface to translate the operator requests into control sequences for the equipment.

For example, that was the case for the vacuum implementation which was implemented by the AT/VA group [37]. Between 1992 and 1996, a new vacuum control system has been installed step-by-step on the different accelerators of the CERN PS Complex (Linac2, Linac3, PS Booster, PS and the related beam transfer lines and LPI machines). The initial goal was to rejuvenate old equipment whose technology was very difficult to adapt to the new control, and to standardise the hardware and software of these different systems. The hardware's two level architecture fits in well with the needs of distributed control. The software is structured in two layers (generic and specific) to obtain a standard interface to all the vacuum equipment for each of the different accelerators; the two layers communicate through the general control protocol.

4.5 Data Base General Description

The accelerator control programs which need information about the accelerator hardware and software configuration can get this from the Oracle relational database with embedded SQL statements. To give application programs fast access to read only data, the DBRT (Data Base Real Time) system was made. It is a simple database (key, value) which is accessed read-only by normal procedure calls which return a single record when given a key. The data in DBRT are downloaded from the Relational Data Base Management System (RDBMS) ORACLE [63].

The DBRT uses the UNIX standard “dbm” facility, where the data reside in two files: a small directory file and a large hash file, containing the data. Identical copies of these two files reside on the server for each accelerator subsystem, allowing them to continue working when other subsystems are down. The application programs are provided with a specific API to hide all the “dbm” calls. There are identical copies of the DBRT data files in servers MCR, LPI, TST, LIN, CPS, PSB.

4.6 The new Analogue signals observation system (nAos)

The operation of the PS machines relies heavily on the use of analogue signals for tuning and diagnostics. The existing analogue switching system was progressively replaced by a digital system using the VXI technology [19]:

- 20 crates are distributed in the CPS technical buildings to provide local multiplexing of signals; in each of these crates 2 to 8 fast oscilloscope modules perform the digitisation of the signals. A controller running under VxWorks manages each crate and provides the link to Ethernet for controls and data transfer. The synchronisation on the beam-type is provided by a PPM information broadcast on Ethernet; the scope triggers, elaborated centrally from machine-related events are supplied on dedicated cables.
- the Oracle database is used to store the system lay-out, the observation settings associated with each signal as well as reference signals, current status of the system and statistics of utilisation.
- a user interface presents 3 virtual scopes regrouping 12 signals independently of the VXI modules which elaborated them. This interface provides all the facilities of the modern oscilloscopes plus the selection of the signals through a tree-like structure, of the triggers and of the beam to be observed. Global selections allow instant access for the operator to all the signals relevant to a specific machine adjustment.

The software has been optimised to reduce the overall delay between the completion of the signal digitalisation and the display to a few tens of milliseconds in order to preserve the possibility for the operator to time correlate the signals to other phenomena. Around 1600 signals are treated and this system is still expanding.

5. NOAS, Operator Interface and Applications.

5.1 Specifications from NOAS (“New Operational Aspect Section”)

The operation interface was the result of a collaboration between the Controls group and the Operation group conducted through studies in the NOAS. It was designed in order to bring to the operator a uniform environment integrating parameter controls, beam measurements, alarms and general information [28].

The pulse-to-pulse modulation (PPM) of the controls which is needed to handle sequentially different types of beams has been redesigned. Each beam is described by a single label (“Users”) which drives directly the machine parameters. Up to 24 independent “Virtual Machines” are now simultaneously available.

5.2 Console

The concept of console has been kept to provide the operator with a sufficient amount of simultaneous information and controls. These consoles currently contain 3 workstations (one of them controlling 2 screens).

Console Manager
To start an operation session on a workstation, the machine to be operated has to be specified. According to this specification a “Console Manager” window is activated presenting pull-down menus through which one can access all the tools needed to operate this machine [13,14]. The Console Manager allows the operator to activate a number of tools which constitute a “Context” [Fig.4]. Several contexts addressing different beam operations can be set-up and stacked. Each of the contexts is linked to a single type of beam for clarity. They are exclusive and occupy a complete screen; the access to any of them is performed through the Console Manager. Although any control can be performed from any workstation, the workstations in the console have been assigned to tasks for a maximum efficiency of the operation.

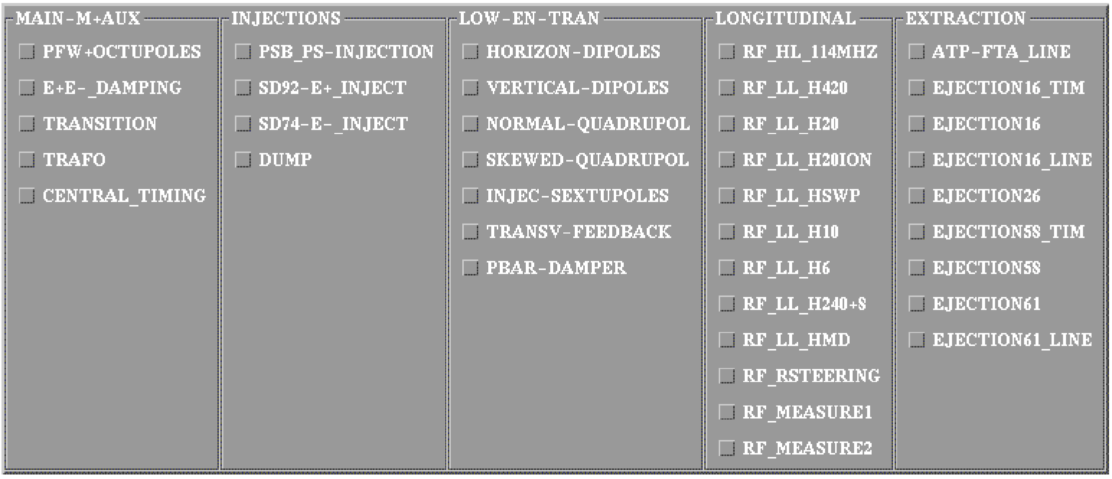

Fig.4 The different “Contexts” of the PS Console Manager

The control section uses the workstation with 2 screens. Each of the 2 screens gets its own Console Manager which can access one of the 8 contexts. These contexts are used to contain the different environments (Working sets/Knobs/Application) prepared to handle the different aspects of the control of the beam currently delivered to the physicists.

- **Working set** windows are activated from the Console Manager; they come as lists of parameters, including for each element: its name, status, control value, acquisition value, units and reference value [Fig.5]. Background colours are used to inform the operator about the status of these parameters as well as warning or error indications. The data is updated on demand or time scheduled (every 4 s). Contrarily to the former control system, these working set parameters are never reserved to a unique workstation.

- **Knob** window appears at the bottom of the screen and presents in a row the knobs which have been activated to perform individual parameter value adjustments. Knobs are interaction boxes providing the user with the visualisation of an equipment element and means for changing its control. All setting commands are built into pull-down menus and control values are managed with a dedicated “wheelswitches” widget, supporting mouse or keyboard interaction. It can also present more specialised information on alternative pages.

- For the console manager tools, each control value of the equipment is mirrored in an Oracle table for "reference values"; they can be updated with the current values or sent back to the equipment (either individually or in blocks). The colour of control and acquisition values (green, yellow or red) reflects whether or not the current equipment value is consistent with the reference value within the defined tolerances.

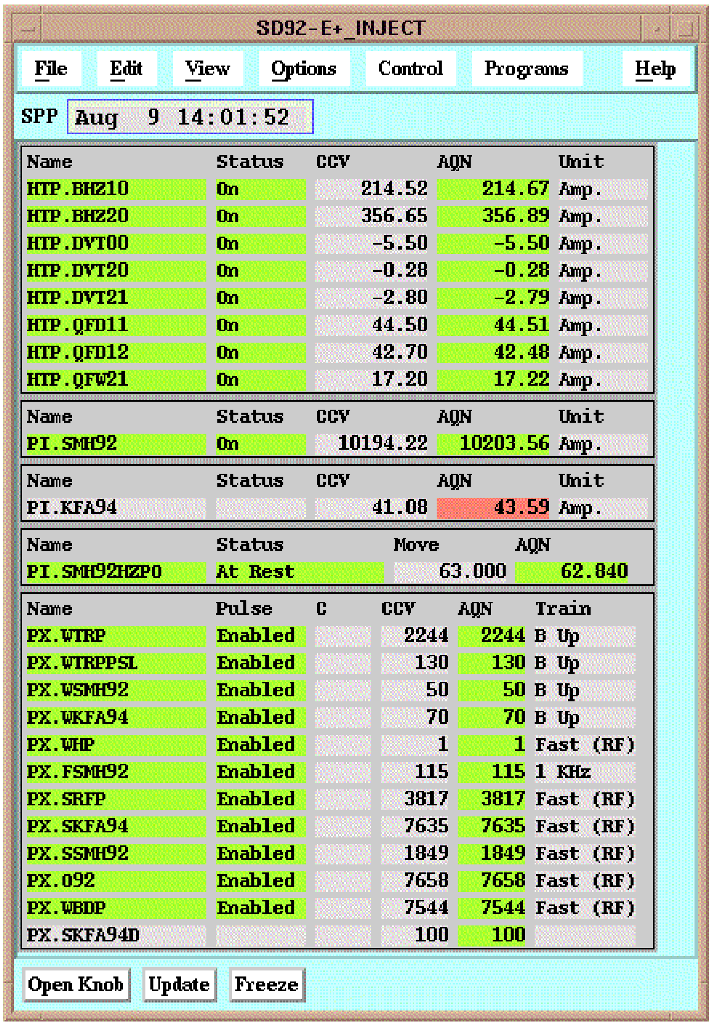

Fig.5 The Working Set of the Positron Injection Operation.

- **Application** Window presents either tools dedicated to some sophisticated setting which cannot be properly performed through knobs or a measurement device with its own controls, graphical or alphanumerical displays. The application programs are activated from the console manager. Machine parameters that would need to be adjusted as part of the measurement procedure can be hooked to knobs from within the application. Whenever possible, these application measurement programs are made generic for a given class of instrument.

- **Archives :** Without coupling between beams, it is possible to store in archives and retrieve easily a complete “virtual machine”. Copy programs capable of duplicating all or part of the parameters of one virtual machine to another are used when identical settings have to be applied to different beams.

The Equipment section exploits the second workstation of the console to display the **"Alarm Handler"**. A continuous survey of the equipment status is performed and the faulty parts are shown. Detailed information is available. Set-up attached tools can restart the equipment which is not really damaged. Alternatively to overcome controls problems not handled by the alarm handler, the equipment handler can be activated on this workstation to access directly the equipment.

The Analogue Signal section needs the third workstation to display the signals produced by the new system based on local VXI multiplexers and oscilloscope-like digitisers described in section 4.6. The same application program drives the selection of the signals and presents virtual oscilloscopes capable of displaying up to 12 signals simultaneously, with a total processing delay < 100 ms.

Control Room environment

Besides the operation consoles other tools are available to help in operating the machines. PCs linked to the "Office" Ethernet network can access the machine parameters through a link towards the "Controls" network ("Passerelle"). This is used by machine development people, developing dedicated and volatile controls application to perform tests and to capture data. The same PCs are also used by the operators to access a logbook readable from any office and as terminals to read databases for schedules, specialists call lists and statistics.

A number of large TV sets around the control room display the most important information coming from the PS machines as well as from the other CERN machines using our beams.

5.3 User interface

5.3.1 Workstation software structure

To fulfil the NOAS requirements and to make the program development more efficient a set of development/run time tools has been provided. A single framework guides the developer through menus and options and provides specific control widgets and displays according to configuration data found in the database. This has proved very valuable for producing new control interfaces with minimal programming effort. An important part of this operator interface is the control of accelerator equipment, and this is implemented with software modules based on the concept of general purpose data-driven programs.

The software of this interface is composed of 3 major modules: the equipment access, the operator interface and the database management [23] :

- **The equipment access** module implements all the communication functions and provides a uniform interface to all the equipment classes. The equipment interface in the workstations provides the resolution from names to equipment identifiers and the distribution of array calls to the relevant front-end computers. Real accesses are implemented by means of the Remote Procedure Call (RPC).
- **The operator interface** module handles the requests from the operator, creates the user-interface, and manages the dialog between the operator and the equipment access. The operator interface is built in an automatic manner using two data stores: the operation configuration and the parameter description.
- **The database management** module provides edition and distribution functions for the data of the other two modules. All data are stored in Oracle tables. The equipment and parameter descriptions, as well as the operation configurations, are distributed as read-only copies to redundant file servers (see section 4.5).

This interface fulfils the programmer requirements and it is well accepted. The emphasis we put on the data structure provides us with an environment where the software is largely independent of the equipment. Equipment additions and modifications are reflected in the data which are the responsibility of the equipment specialist.

5.3.2 Operational Applications Programs, Realisation, Frames

Application programs can be either dedicated to special instruments or to high level control or they can be generic. Generic application programs were mainly developed by the CO group while dedicated programs were implemented by end-users for all specific applications. The interfaces with the control system (e.g. equipment access) are provided by control system libraries.
Generic measurement programs provide a uniform operator interface to various instances of the same class of instrument. These programs use the working-set data in order to build, in an automatic manner, the measurement display, the instrument control and the connections to other measurement or correction elements. The following programs have been implemented: beam profiles with SEM-grids, beam intensity with transformers and trajectories with pick-ups.
Equipment logs are produced for file archives or for printing (monochrome or colour). They indicate values and settings of sets of equipment elements with a warning or error status (this includes reference and acquisition checks).

6. Exploitation & Diagnostic Tools

The performance of the CPS Control System depends largely on the capabilities of the exploitation team to maintain its hardware and software components in an efficient way [41]. That efficiency relies on the continuous training of the persons, the documentation of the hardware and software components of the control system, the communication between the developers and the members of this team, but also on the tools provided to this team to be able to diagnose, recover, restart and/or set-up the components of the control system. Data logging of the element values, easy access to the repository data base (ORACLE), automated software re-configuration of front end processors (from the data base), tracing and logging of faults with post mortem analysis capabilities, on-line testing and set-up facilities are the main tools used by the members of the exploitation team to fulfil correctly their first priority job.

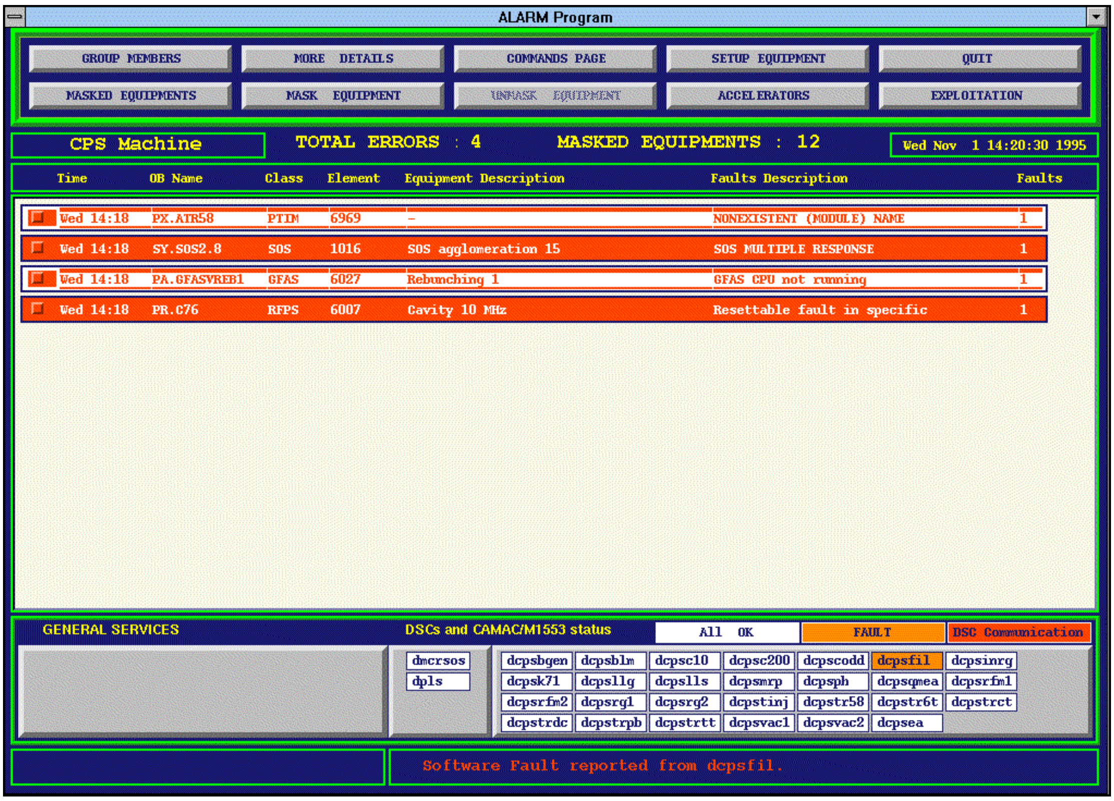

Fig.6 The window of the Alarm program panel for the PS.

The status of the different controlled elements of the CPS complex are permanently monitored on the screens of the Control Room workstations, in a window generated by the **Alarm** process [21, 30] [Fig.6]. The detection of equipment alarms has been incorporated into the equipment access software layer, through a uniform Equipment Module property, which can return an alarm indication, for all classes of equipment. This program, used both by operation and exploitation crews, scans every 30 seconds the status of the controlled equipment via the uniform equipment access level (Equipment Modules). In addition, it surveys also the VME and CAMAC crates, both for overall hardware and software status. The alarm process is the main entry point for diagnosis tools and information. It allows the presentation of :

- the details of faulty equipment (control, analogue signal)
- the layout of input/output crates (VME and CAMAC): modules of the crate, equipment controlled
- the VME Processor status : accessibility, interrupts and errors
- the log of the faults, the pulsed status and the interrupt layout of the timing system elements

From this information one can detect a fault at the element level (like a power supply, a vacuum pump, a RF cavity, ...) and reset a faulty piece of equipment. A VME processor not accessible by the control system can be remotely rebooted after verification of its status. The history of the reboots and the errors are logged and can be displayed on request.

Almost all the exploitation tools can be called through this **Alarm panel**, either directly or through two important programs :

The general program, **Equipment Info,** gives the possibility of selecting dedicated programs to diagnose, test, initialise a piece of equipment or a control interface; this is especially the case for the different instrumentation and field buses (CAMAC and MIL1553). One can also test a particular piece of equipment, access it and initialise it if necessary. Special debug or repair commands, Equipment Module documentation and the layout of subsystems (timing systems for example) are also available from this general panel of services. From another special panel, an equipment can be tested or controlled through specialised Equipment Module properties.

The second general program, the **Set-up,** is created to automate the reinitialising of a piece of equipment or a whole system (a CAMAC crate for example). The set-up provides means for initialisation and for non-destructive testing for the accelerator equipment based on CAMAC and VME control interfaces [22, 29, 31]. It is a rule based process which can cope with any unknown initial state of the equipment. The primary uses are after a power fail, a shut down or a replacement of a faulty hardware module or crate; the set-up allows the initialisation of the hardware with the correct sequence of procedures and the correct operational values (last saved values). The set-up is used also to reset faulty equipment (a power supply for example) to come back to the normal state. When instrumentation gives wrong information or does not run correctly, the best solution is to call the set-up which is more clever than the alarm reset, due to its rule based actions. Finally, the set-up can also test equipment without disturbing or with the minimum disturbance of its normal functioning. The set-up system can easily be customised to any control system component. The set-up facility is a derived product of the European Community Esprit II project, ARCHON.

A few other important tools exist, which can be called for a specific purpose. This is the case:

- for the set-up, surveillance and display of the different chains of timing pulses; several programs give the possibility to compare the controlled value of the timing pulse with the real output of this pulse acquired by a special VME module, the TSM (Timing Surveillance Module).
- for the verification of the description and synchronisation of the different operations of the CPS accelerator complex, where a rule-based analyser can be called to verify if the required schedule is coherent and acceptable, the Beam Card Desk Checker.
- for the automatic configuration of the software of front end processors (DSC), directly from the data kept in the ORACLE data base (see chap. 4.5)

- for the Data Browser/Editor (BRED) which gives the possibility of reading, comparing and modifying the read-only values stored in the data table of the Equipment Access modules (Equipment Module); with this tool, the exploitation team can work on the actual operational data, the regularly saved values and the values called references.

7. Evolution of the CPS Control System

7.1 Migration to IBM workstation (already done)

During the implementation of the control system of the CERN PS accelerator complex, it was necessary to select another type of workstation. The Digital DEC MIPS type was no longer produced and the new version was partially software incompatible with the previous one. The IMB RISC/6000 was selected. It was then necessary to review the software primary used as user interface and to port to IBM workstations. On this occasion was performed a general cleaning of the code and file system to ease the maintenance with minimal staff. This implies a clear separation between general computing facilities, control system developments, and operation. These changes were done during 1995 and 1996 and were completed beginning 1997 with the move of the ORACLE Data Base on the IBM file servers [40].
Presently a total number of 110 workstation IBM RISC/6000 43P (8 of which are double screen) and 12 file servers C20 are connected and in use on the network. The servers are located in a control room (MNR), just underneath the Main Control Room (MCR); the MCR and local control rooms are equipped with workstations, while equipment areas and offices use either workstation or X-Terminals.

7.2 Processors embedded in VME crates

The decision to use MVME147 was taken in 1990; it was based on the Motorola MC68030 chip; but later the MVME167 based on the MC68040 chip was selected to follow the technological improvement. Up to beginning 1997, this line was continued. Unfortunately, the onboard memory of these processors is 8MB which became definitively too small.
In-between, the SL/CO group, for the purpose of replacing the 70 IBM/PCs used in the LEP and SPS control systems by VME based systems, decided for the PowerPC boards. The price of PowerPC boards is now lower than the MVME167 at equivalent memory sizes. So the decision was recently taken to move towards this kind of CPU in the PS, as this would ease collaboration between the two control groups [38]; but this change is outside the scope of the D067 project.
This new generation of PowerPC VME processor modules, running the LynxOS real-time operating system, using the state-of-the-art microprocessor technology will be first introduced in the next implementation of the CPS AD (Antiproton Decelerator) control system (1997/1998). Porting the general CPS environment towards this platform (devices drivers , libraries ,utilities , Equipment Modules) is just now beginning.

7.3 Structured Control Network

In the context of the consolidation of the PS Complex, the PS Controls group is launching the rejuvenation of the PS controls network dealing with on-line equipment that is used to run the machines of the PS Complex and that requires a high reliability and fast repairs. This gives the opportunity to IT/CS group to use part of this new equipment to upgrade also the public network which links the workstations and PCs in the office buildings plus the controls equipment of the physicists in the experiment halls.
The study and the implementation of this new controls network will be realised in common with the SL/CO group so that the equipment and service can be unified for all the beam production chain over CERN.

From end of 1997 to mid 1998, it is foreseen to provide the structured cabling in building 354 (MCR, MNR, CCR), the communication network for the new AD machine and the renewal of the East Hall network. The PSB area will then be cabled in 1999 and the PS Central Building in 2000. As mentioned earlier, IT/CS provides at the same time the necessary extensions of the public network in the offices and in the halls. A sector project has been launched to manage the whole work.

7.4 Field Buses & Industrial control modules

The use of new field buses (CAN Bus, PROFIBUS and WORDFIP as recommended by a CERN wide study) and industrial control modules (PLC : Program Logic Controller) could be envisaged in the case of simple, non PPM power converters. For the moment, the lack of resources in the Power group and the priority work imposed by the different CPS projects have delayed the studies and the implementation of these devices in the CPS control system. Studies and use of low cost CAN Bus are in progress for control of the proton source of linac2[66].

7.5 Digital Video Signal Observation System

The digital video system handling was ported to the DSC environment in 1995, allowing the removal of the dedicated NORD computer. Nevertheless, the equipment was built in the early 1980s and needs to be replaced. The solution of local digitisation is currently being explored through two studies respectively in the BD and the CO group.
This solution implies large data transfer through the network and powerful processors to cope with the real time constraints. The aim is to have the new system working before the end of the LEP.

7.6 Software : ABS, Data Base for Accelerator, Modelling.

The Automated Beam Steering and Shaping (ABS) project aims to provide an automatic, generic and reliable system to ensure the provision of high quality particle beams to users of an accelerator complex. A generic and modular software is developed whose purpose is to end up with a data-driven, and portable application package that has a common look and feel for the different machines and transfer lines, and for the different types of corrections. The programs have interfaces to several different instrumentation devices, normally external software applications, used to measure the actual beam positions or shapes. For calculation of new machine settings, the programs use the CERN developed Mathematica-based program BeamOptics [61].

An important component of this project is the access to validated reference data describing the different components installed in the machines, such as monitors and magnetic properties of all magnets. These properties are dependent on the type of particle, on the energy and on the destination of the beam to be treated. The data model must therefore be able to represent several particle beams along different trajectories through the same element. Furthermore, the database design must be sufficiently generic to allow the description of all magnetic elements from a simple dipole to complex multi-coil magnets. For a given operation, the sequence of optics elements with the parameters appropriate to the type of beam must be extracted, suitably formatted and passed as input to a beam optics program. This important project which will change the day-to-day operation of the machines is presently under development [65].

8. Conclusion

The main aspect of the "Standard Model", as implemented in the CERN Accelerator Common Control System, is an architecture which permitted continuous upgrading, as the technologies evolved. The main components of the Common Control System are based on open standards, so that the hardware and the software became more independent of the manufacturers. In the implementation of the CPS part of the Common Control System, a large part of the existing hardware investment has been preserved, and the inter divisional collaboration has been kept alive during the step by step integration. The common convergence policy was based on well established industrial standards for control networks, communication protocols, equipment, operating systems and man-machine interfaces. As much software as possible was written to be independent of the development platform, leaving open the possibility of transferring application programs between the CERN accelerators in the event of a unique control room being envisaged for the very different accelerators existing on the CERN site.

The collaboration with the hardware specialists, accelerator physicists and operation professionals of the CPS was a daily fact during the control system implementation, and it is now continued with the other CERN accelerator divisions as well as with other laboratories. The software (and hardware) sharing reduced the duplication of effort and the use of external expertise. The utilisation of commercial products complemented this exchange in a period where the lack of manpower and the cuts of budget allocations necessitated a lot of imagination and a drastic increase in productivity.

The collaboration established with the SL Control group since the design of the project was continued all along the length of the different slices, for the software, hardware and budget support. Synchronisation and timing, VME modules and processors, field buses, network and data base, were the most visible systems where this collaboration ended up with common solutions, but the common studies continue and even more are needed.

The main management and strategic parameters applied for the rejuvenation of the CPS control system were :

- step by step implementation according to the yearly machine schedule of the complex, without disturbing the production of particles,
- adaptation of the project following the external constraints (cuts in yearly budget allocation, change of priority, new accelerators) without forgetting the initial goal which was to eliminate as soon as possible the obsolete NORD mini computers
- utilisation of standard hardware and software to accommodate the external decisions
- modification to the general budget profile of the project over the years to integrate the changes in a regular manner, bringing to mind the delayed items and including the evolution of the price of computer equipment.

Acknowledgements :

This report summarises the work of tens of persons in different groups and divisions of CERN. Many of the participants can be found in the references which are taken from the Proceedings of the main conferences on Controls and Accelerators, and from PS or SL internal reports.

We acknowledge the continuous support of the PS Division and the leadership from R.Billinge, K.Hubner, DJ.Simon, and D.Blechschmidt, B.Allardyce for the budget. The Accelerator Department Heads G.Plass and K.Hubner advocated the D067 project and tried to fund it correctly, in spite of the different cuts in the budget; especially we have to thank K.Hubner for the resources given during the abrupt change of workstation and servers. We received assistance and encouragement from the SL Division all along our collaboration for this common project, and we want to express our gratitude to L.Evans, K.Kissler and R.Lauckner.

Appendixes :

1. Design of the CERN Accelerator Common Control System (1990/1991)
2. Budget D067 : Foreseen, Granted and really Spent (1991-1997).
3. Resources CO spent (and guesses of CPS groups)
4. Equipment installed during the D067 project.
5. Still to be done**.**

References :

A PS/CO Note details the PS complex implementation slices between 1991 and 1997 :
Ch.Serre, Realisation of the D067 Project :Sequence of events of the implementation of the CPS Accelerator Complex Control System, PS/CO Note 97-31, 4.08.97, revised March 98**.**

WEB address for the PS/CO Control system updated information :

http://psas01.cern.ch/Welcome.html
http://www.cern.ch/Divisions/PS/CO/Welcome.html

Appendix 1
Design of the CERN Accelerator Common Control System.

Preparation of the Project (1990-1991) based on :

- PS & SL Division collaboration
- Common Control System for CERN Accelerators
- Software & Hardware inventories of existing interfaces and modules
- Reflection on priorities, transition periods, resources
- Presentation to be done for end 1990, for DG agreement

Discussions and Design :

- Inventory & Planning Team
- Creation of two Working Groups
- AWG : Applications ➔ from 27.03.90 to 8.02.91
- DWG : Architecture & DSC ➔ from 22.03.90 to 17.04.91
- Study team on Protocols (created on 10.08.90)

Creation of CUF : Control User Forum

1rst CUF in Chamonix, 25/28 April 1990.
Presentation of the different Control Systems
Discussion of User's Needs
Inventory of control equipment
Planning of the design

2nd CUF in CERN/SL, 27.06.90.
Review of the work done by the 2 WG (AWG & DWG) and the User's Groups
Objectives to be reached for the end of 1990.
For the CPS Control System :
Control Hardware : 23 computers Norsk Data
260 CAMAC crates (120 crates with ACC/SMACC)
Prototype foreseen : Installation of 3 workstation in MCR
Design and test of a MMI for 1 Gev Injection in the PS
DSC interface for LPI (with instrumentation on VME)

3rd CUF in CERN/PS, 21.11.90.
Draft Reports of AWG and DWG distributed
Presentation of Software for Applications and MMI by AWG
Presentation of Architecture, DSC and Protocols by DWG

Distribution of the Technical Report [7] in April 1991.

D067 Project :
Project Leaders : KarlHeinz Kissler/Fabien Perriollat.
Title : PS/SL Controls Consolidation.
Originally approved in August 90, signed by DG (C.Rubbia) on 7.6.91
Purpose : Replacement of the 16 bit Norsk Data Computers
Replacement of old electronics interfacing the Equipment
Initial Planning for CPS :
Five slices foreseen from 1991 to 1995 (LPI, PSB, CPS, TT+LIN2, AAC/LEAR)

Appendix 2
Budget D067 : Foreseen, Granted and really Spent (1991-1997).

As stated in the introduction, the amount of the budget for the Rejuvenation Project of the Control System of the Accelerators includes the general Controls Infrastructure, plus the Specific control interface of the CPS Equipment.

Summary of the yearly amount requested, received and spent (1991/1997)

ChS./ 26.8.1997	91 FEC91	92 LIN92	93 PSB93	94 CPS94	95 TT95	96 CONS96	97	
CPS Machines transferred to the new CS :	LPI	LINAC 2	PSB	PS-1 Inj+RF	PS-2 Ejection Tr. Lines	Consol. LPI PSB,CPS	Report	TOTAL
D067: Requested for PS	**937**	**1701**	**2672**	**3405**	**1595**	**1714**		**12024**
D067 Budget RECEIVED for PS	900	1700	980	1500	1760	2070		
	250		150		700	0	360	
Total Received	1150	1700	1130	1500	2460	2070	360	**10370**
Amount really SPENT on D067	1820	1477	1350	2305	2758	2523	484	**12717**

	PS	SL amount
At the opening of the D067 Project (15.02.91), the amount foreseen for the PS was : (including AAC and LEAR)	**14509 KFS**	**14477 KFS**
After a first revision (5.10.92), the part of the PS (with AAC/LEAR) was :	**12808 KFS**	**13192 KFS**
The last revision at the end of 1993 for the PS (without ACC/LEAR) gave the final amount :	**12024 KFS**	
BUT the total received (DG + Department) was only :	**10370 KFS**	

ONLY with the help of the Exploitation Budget of the PS Division was it possible to spend a total amount of

12717 KFS

Appendix 3
Manpower for D067 (CO resources and CPS groups estimates)

This table tries to summarise the total amount of man/year spent for the realisation of the D067 Project in the PS Division (+AT/VA for the vacuum).

The data for the CO group are the result of the information given monthly by the CO participants during the project. These data can be considered as reliable and correct. The data reflects the direct participation to the D067 project implementation, not the exploitation or the follow up done mainly by the exploitation section of CO.
The other components are estimations (guess) either from the group leaders or from the project management (taking into account the different people concerned during the sequence of the slices); it concerns only the control part of the interface, not the associated work, studies or consolidation.

Year	done	CO	PO	OP	BD	RF	PA	HI	LP	AT/ VA
90	**Studies**	**7.5**								
91	**LPI**	**13.8**								
92	**Linac2**	**13.4**								
93	**PSB**	**12.2**								
94	**CPS-1**	**17.1**								
95	**CPS-2**	**11.2**								
96	**Consolidation**	**10.9**								
97		**2.5**								
	Man-year	**88.6**	**19.5**	**17.0**	**15.1**	**10.8**	**5.0**	**4.8**	**2.0**	**5.1 ?**

The estimated total is : **170 man-year**

Without the year 1990 and 1997, the mean value of the manpower utilised for the D067 project is:

27 my/y , i.e. 160 my in 6 years.

and for the Control group : **14 my/y** , i.e. 80 my in 6 years.

Appendix 4
Equipment installed during the D067 project.

1. DSC (VME crate) and VXI crate.

100 VME crates (DSC) linked to the control network of the CPS machines

- 38 for the PS machine and Transfer Lines
- 4 for the CTF2
- 13 for the LPI (LIL and EPA)
- 7 for the Linac2
- 9 for the Linac3
- 25 for the Booster (including one for Isolde)
- 4 for the central Timing and SOS (MCR)

(plus 16 to 17 for AD machine)

40 VME crates are identified as "Test DSC" (11 for CO group and 8 for BD group)

20 VXI crates are installed for the nAos system (presently 1600 signals) plus 2 for AD.

2. MIL 1553/G64 connections.

58 Bus 1553 are controlled by the DSC for the CPS machines (with a total of 723 RTI)

- PS machine and Transfer Lines : 24 Bus and 356 RTI
- CTF2 : 2 Bus and 12 RTI
- LPI : 8 Bus and 17 RTI
- Linac2 : 9 Bus and 158 RTI
- Linac3 : 6 Bus and 110 RTI
- Booster : 7 Bus and 70 RTI

Each RTI module (link between the 1553 Bus and a control channel) does not correspond directly to a G64 crate; especially the control of the power converters could be done with 1, 2 or 4 control channels for one G64 bus.

A total of 582 power converters, 22 modulator status and associated, 56 RF cavities and RF parameters, 63 stepping motors, are controlled through 1553/G64 channels.

3. CAMAC crate.

A total of 97 CAMAC crates are still presently connected to DSC on the control network :

84 CAMAC crates for the control of the different CPS machines

- 21 for the PS machine and Transfer Lines
- 30 for the LPI
- 5 for the Linac2
- 1 for the Linac3
- 18 for the Booster
- 9 for the CTF2

13 CAMAC crates for the old SOS system and the old PLS telegram transmission

(+ some crates for Test and Miscellaneous)

4. Miscellaneous.

Several parameters are controlled directly via VME modules (GFAS, IOR, DOR or specific ones); a lot of acquisition parameters are treated also via VME modules (ADC for example).

Appendix 5
Still to be done :

During the D067 project implementation, the LPI and the Booster machines suffered from lack of money and manpower to be converted as it was foreseen. The PS machine and transfer lines were mainly affected for the instrumentation, while for the other equipment still controlled by CAMAC, the CPS Conversion Project plans to progressively replace the present CAMAC controlled channels.

LPI :
The main question is to know whether the conversion is to be done, depending of the future of LPI machine after the end of LEP (foreseen for end 2000).

- 7 modulators
- 130 power converters (LIL, EPA, Transfer) + 33 LIL power converters (steering, bumper)
- the general timing
- RF and Gun equipment (with stepping motor)
- Instrumentation (UMA control, MTV, SEMgrids, Stepping motors)

are still CAMAC controlled (30 crate). The electronic of the power converters are already converted to G64 crate, but linked with Quad/Single.

Booster :
During the Booster step (1993/1994), the budget was cut drastically and we were obliged to switch to the less expensive solution, especially for the power converters (312 units) and the Instrumentation.

- Recombination and PSB/PS line (will be converted for “PS for LHC”)
- ISOLDE transfer line
- Ring correction + Ring correction dipoles (wait on GEB decision)
- Shavers and Beamscope
- Old TEMPX equipment
- SEMgrids, MTV, Beamscope, Longitudinal Emittance, BTFM, transfer transformer

are the main equipment still on CAMAC.

PS & transfer lines :
During the last three steps (1994/1997) the PS equipment was correctly converted; still not converted are :

- Transverse Feedback
- SEMgrids, MTV, SEC and Telescopes, Q Measurement interface
- Some TSM, TDC and Decoder modules
- BFA & DFA supplies
- KFA 72 & 94 control

Linac2 :
Only two systems are not yet converted :

- the specific system for selection and observation of Linac2 analogue signals
- the control of the proton source (already in study)

General :

- replacement of the 12 CAMAC crates of the old SOS Video signal system
- replacement of the CAMAC interface for the CTF2 equipment
- replacement of the CAMAC control and acquisition of the SEMgrids

References:

ICALEPCS 89, Vancouver, BC, Canada, October 30 - November 3, 1989

1. F.Perriollat, Ch.Serre, “Problems in rejuvenating a control system and plans for the CERN proton Synchrotron (CPS)”, ICALEPCS, Vancouver, Canada, October 30-November 3, 1989, Nucl. Instr. And Meth. A293 (1990) 81

2. PG.Innocenti, “The LEP Control System”, ICALEPCS, Vancouver, Canada, October 30-November 3, 1989, Nucl. Instr. And Meth. A293 (1990) 1

3. B.Kuiper, “Accelerator controls at CERN: some converging trends”, ICALEPCS, Vancouver, Canada, October 30-November 3, 1989, Nucl. Instr. And Meth. A293 (1990) 308

4. L.Casalegno, J.Cuperus, Cl-H.Sicard, “Process equipment data organisation in CERN PS controls”, ICALEPCS, Vancouver, Canada, October 30-November 3, 1989, Nucl. Instr. And Meth. A293 (1990) 412

5. R.Bailey, G.Baribaud, G.Benincasa, "Operational protocol for controlling accelerator equipment”, ICALEPCS, Vancouver, Canada, October 30-November 3, 1989, Nucl. Instr. And Meth. A293 (1990) 332

6. G.Benincasa, L.Casalegno, G.Gelato, “Implementation of a control protocol in the instrumentation field”, ICALEPCS, Vancouver, Canada, October 30-November 3, 1989, Nucl. Instr. And Meth. A293 (1990) 338

PS & SL Notes in 1991

7. The PS and SL controls groups, "PS/SL Controls Consolidation Project", Technical Report, CERN PS/91-09(CO), CERN SL/91-12(CO), April 91.

PAC91, San Francisco, USA, May 6-9, 1991

8. GP.Benincasa, G.Daems, B.Frammery, P.Heymans, F.Perriollat, Ch.Serre, C-H.Sicard, “Rejuvenation of the CPS Control System : the first slice”, Proceedings of 1991 Particle Accelerator Conference, San Francisco, USA, May 6-9, 1991.

ICALEPCS 91, Tsukuba, Japan, 11-15 November, 1991

9. R.Rausch, Ch.Serre (editors), "Common Control System for the CERN Accelerators", ICALEPCS 91, Tsukuba, Japan, 11-15 November 1991, p.54-58

10. KH.Kissler, R.Rausch, “New Control Architecture for the SPS Accelerator at CERN”, ICALEPCS 91, Tsukuba, Japan, 11-15 November 1991, p.59-64

11. A.Gagnaire, N. De Metz-Noblat, Ch.Serre, C-H.Sicard, “Replacing PS Controls Front End Minicomputers by VME based 32-bit Processors”, ICALEPCS 91, Tsukuba, Japan, 11-15 November 1991, p.375-377

12. W.Heinze, “Driving Serial CAMAC systems from VME crates”, ICALEPCS 91, Tsukuba, Japan, 11-15 November 1991, p.386-388

13. P.Antonsanti, M.Arruat, JM.Bouche, L.Cons, I.Deloose, F.di Maio, “Workstations as Consoles for the CPS complex, setting-up the environment", ICALEPCS 91, Tsukuba, Japan, 11-15 November 1991, p.446-451

14. M.Boutheon, F.di Maio, A.Pace, "General Man-Machine Interface used in Accelerator Controls; Some Applications in CERN-PS Control System Rejuvenation", ICALEPCS 91, Tsukuba, Japan, 11-15 November 1991, p.452-455

15. G.Baribaud, I.Barnett, G.Benincasa, O.Berrig, R.Brun, A.Burns, R.Cappi, G.Coudert, C.Dehavay, B.Desforges, R.Gavaggio, G.Gelato, H.K.Kuhn, J.Pett, R.Pittin, JP.Royer, E.Schulte, C.Steinbach, P.Strubin, D.Swoboda, N.Trofimov, L.Vos, "Control Protocol : The Proposed New CERN Standard Access Procedure to Accelerator Equipment. Status Report", ICALEPCS 91, Tsukuba, Japan, 11-15 November 1991, p.591-594

16. C.G.Beetham, G.Daems, J.Lewis, B.Puccio, "A new VME Timing Module", ICALEPCS 91, Tsukuba, Japan, 11-15 November 1991, p.360-363

PS Notes in 1992

17. A.Pace, F.Perriollat, "Experimental Introduction of PC Hardware and Software at Console Level in the CERN PS Control System", CERN PS/CO/Note 92-03, February, 1992

18. I.Deloose, V. Garric, A. Pace, "Equipment Access from the Office Network", CERN PS/CO/Note 92-15, September 1992

RT-93, Vancouver, BC, Canada, June 8-11, 1993

19. B.Dupuy, P.Fernier, B.Frammery, S.Passinelli, “A VXI System for the observation of distributed analog signals”, Proceeding of RT-93, Vancouver, BC, Canada, June 8-11, 1993, IEEE Transactions on NS, Vol.41, 1, Feb.94, 209.

ICALEPCS 93, Berlin, Germany, October 18-23, 1993

20. F.Perriollat, Ch.Serre, “The new CERN PS control system, Overview and status”, ICALEPCS, Berlin, Germany, October 18-23, 1993, Nucl. Instr. And Meth. A352 (1994) 86

21. J-M.Bouche, J.Cuperus, M.Lelaizant, “The data driven alarm system for the CERN PS accelerator complex”, ICALEPCS, Berlin, Germany, October 18-23, 1993, Nucl. Instr. And Meth. A352 (1994) 196

22. G.Daems, V.Filimonov, V.Khomoutnikov, F.Perriollat, Yu.Ryabov, P.Skarek “A knowledge based control method : application to accelerator equipment Setup”, ICALEPCS, Berlin, Germany, October 18-23, 1993, Nucl. Instr. And Meth. A352 (1994) 325.

23. J.Cuperus, F.di Maio, CH.Sicard, "The Operator Interface to the Equipment of the CERN PS Accelerator Complex", ICALEPCS, Berlin, Germany, October 18-23, 1993, Nucl. Instr. And Meth. A352 (1994) 346

24. G.Cuisinier, F.Perriollat, P.Ribeiro, A.Kagarmanov, V.Kovaltsov, "Nodal - The second life of the Accelerator Control Language", ICALEPCS, Berlin, Germany, October 18-23, 1993, Nucl. Instr. And Meth. A352 (1994) 94.

25. H.Abie, G.Benincasa, G.Coudert, Y.Davydenko, C.Dehavay, R.Gavaggio, G.Gelato, W.Heinze, M.Legras, H.Lustig, L.Merard, T.Pearson, P.Strubin, J.Tedesco, "Control Protocol: Large Scale Implementation at the CERN PS Complex", ICALEPCS, Berlin, Germany, October 18-23, 1993, Nucl. Instr. And Meth. A352 (1994) 265

26. W.Heinze, R.Maccaferri, “An inexpensive analog function Generator in VME standard”, ICALEPCS, Berlin, Germany, October 18-23, 1993, Nucl. Instr. And Meth. A352 (1994) 147

27. J.Lewis, V.Sikolenko, "Providing the New CERN PS Timing System", ICALEPCS, Berlin, Germany, October 18-23, 1993, Nucl. Instr. And Meth. A352 (1994) 91

EPAC94, London, UK, June 27-July 1, 1994

28. J.Boillot, B.Frammery, E.Wildner, “The CERN PS controls system Operational Aspects”, EPAC94, European Particle Accelerator Conference, London, UK, June 27-July 1, 1994.

PS Notes in 1994

29. J-M.Bouche, G.Daems, V.Filimonov, V.Khomoutnikov, Yu.Ryabov, “Knowledge based Set-up facility”, 22.11.94, PS/CO/Note 94-81

PS Notes in 1995

30. J-M.Bouche, “Utilisation du programme Alarm”, 6.03.95, PS/CO/Note 95-17

RT95, East Lansing, MI USA, May 23-26, 1995

31. J-M.Bouche, G.Daems, V.Filimonov, V.Khomoutnikov, F.Perriollat, Y.Ryabov, “Representation and Usage of knowledge for Initialization of accelerator control equipment”, Proceeding of RT-95, East Lansing, MI USA, May 23-26, 1995

ICALEPCS 95, Chicago, Illinois, USA, October 30 - November 3, 1995

32. F. di Maio, J. Meyer, A. Götz, “Towards a Common Object Model and API for Accelerator Controls”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p.105

33. J.Cuperus, A.Gagnaire, “Automatic Generation of Configuration Files for a Distributed Control System”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995

34. R.Garoby, M.Gourber-Pace, S.Hancock, F.di Maio, N. De Metz-Noblat, “Controls Upgrade of the RF Systems of the CERN PS”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p. 543

35. M.Beharrell, G. Benincasa, JM.Bouché, J.Cuperus, M.Lelaizant, L.Merard, “Model based, detailed fault analysis in the CERN PS complex Equipment”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p. 474

36. J.Lewis, P.Skarek, L.Varga, “A rule-based consultant for accelerator beam scheduling used in the CERN PS complex”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p. 703

37. R.Gavaggio, P.M. Strubin, “The New Vacuum Control System of the CERN PS Complex”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p. 538

38. A.Bland, P.Charrue, F. Ghinet, P.Ribeiro, M. Vanden Eynden, “The New Generation of PowerPC VMEbus Front End Computers for the CERN SPS and LEP Accelerators Control System ”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p.74

39. F.Momal, C. Pinto-Pereira, “Using World-Wide-Web for Control Systems”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p.62

40. N. de Metz-Noblat, “Migrating the CERN PS control system to IBM workstations”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p. 663

41. G.Daems, F.Perriollat, Ch.Serre, “ Experience in the exploitation of a large control system”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p. 1056

42. P.Charrue and M. J. Clayton, “The New Controls Infrastructure for the SPS”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p. 828

43. R.Lauckner and R. Rausch, “SPS and LEP Controls, Status and Evolution towards the LHC Era”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p. 457

44.M.Rabany, “A Proposal to Move from the LEP Topological to an LHC Functional Control System Architecture”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995

45.M.Rabany, “Industrial Control Solutions in Research Laboratories”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995, p. 392

46.Daniel J. Ciarlette and Rodney Gerig, “Operational Experience from a Large EPICS-Based Accelerator Facility”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995

47.J.Dalesio, M. Kraimer, W. Watson, M. Clausen, “Distributed software development in the EPICS collaboration”, ICALEPCS 95, Chicago, Illinois USA October 30 - November 3, 1995

EPAC 96, Sitges, Spain, June 10-14,1996.

48.A.Campbell, A.Gagnaire, R.Garoby, S.Hancock, W.Heinze, JM.Nonglaton, C.H.Sicard, “A VME-based system for RF parameters in CERN PS”, EPAC 96, Sitges, Spain, June 10-14,1996.

CERN PS & SL 1996 and 1997

49.Th.Salvermoser, “Graphical magnet model”, PS/PO/Note 96-16 (Tech.), May 15, 1996

50.G.Cyvoct, M.Lindroos, “Software Specification for the new MPS application program”, PS/OP/Note 96-19 (Spec.), May 17, 1996

51.J.Lewis, “About the CPS and PSB MPS control”, PS/CO/Note 96-37 (Tech.), June 3, 1996.

52.B.Bleus, J.Schipper, “General description of the fast ejection kicker control and acquisition system (KSU)”, PS/PA/Note 96-18, May 20, 1996.

53.J.Lewis, “What are we planning to do to the MTG” and “First thoughts on Equipment Access to the MTG”, private communications, March, 1996.

54.JC.Bau, “Nouveau MTG : Specifications de developpement logiciel”, PS/CO/Note 96-38 (Spec.), June 18, 1996.

55.W.Heinze, J.Lewis, “Hardware Description of Master Timing Generator (MTG)”, PS/CO/Note 96-73 (Tech.), December 9, 1996.

56.B.Puccio, “The VMTG Hardware Description”, SL-Note 97-xx CO, July 30, 1997

57.B.Puccio, “The TG8 Hardware Description”, SL-Note 97-31 CO, April 4, 1997

58.V.Kovaltsov, B.Puccio, “The TG8 Firmware Description”, SL-Note 97-32 CO, April 4, 1997

RT97, Beaune, France, September 22-26, 1997.

59. J.C.Bau, G.Daems, J.Lewis, J.Philippe, "Managing the real-time behaviour of a particle factory: the CERN-PS timing principles", Submitted to RT97, Beaune, France, September 22-26, 1997.

60. L.Giulicchi, C.H.Sicard, "Design of a remote data subscription mechanism", Submitted to RT97, Beaune, France, September 22-26, 1997.

ICALEPCS 97, Beijing , China, November 3-7, 1997.

61. M.Arruat, A.Jansson, F.di Maio, GH.Hemelsoet, M.Lindroos, O.Tungesvik, "Generic Automated Beam Steering and Beam Shaping Programs with an Object Oriented Approach", Submitted to ICALEPCS 97, Beijing , China, November 3-7, 1997.

62. M.Arruat, F.di Maio, N.Gomez-Rojo, Y.Pujante, "Recent Developments in the Application of Object Oriented Technologies in the CERN PS Controls", Submitted to ICALEPCS 97, Beijing , China, November 3-7, 1997.

63. J.Cuperus, M.Lelaizant, "Integration of Relational Database in the CERN PS Control System", Submitted to ICALEPCS 97, Beijing , China, November 3-7, 1997.

64. F.Caspers, W.Heinze, J.Lewis, M.Lindroos, Th.Salvermoser, "An Alternative to Classical Real-time Magnetic Field Measurements using a Magnet Model", Submitted to ICALEPCS 97, Beijing , China, November 3-7, 1997.

65. B.Autin, F.di Maio, M.Gourber-Pace, M.Lindroos, J.Schinzel, "Design and Implementation of a Database for Accelerator Optics", Submitted to ICALEPCS 97, Beijing , China, November 3-7, 1997.

66. G.Grawer, W.Heinze, "Using a Fibre Optic CAN Bus for the Proton Source Control of the CERN PS Linac", Submitted to ICALEPCS 97, Beijing , China, November 3-7, 1997.