ACCELERATOR CONTROLS

Fabien Perriollat

CERN, Geneva, Switzerland

Abstract

Controls systems are getting more and more important for the running of High Energy Physics Laboratories, due to the ever increasing complexity of the different accelerators used. The problems of accelerator control are explained from the computer science point of view. The major domains of the control systems are studied with the various software techniques used. Some fields of the current development and research will be reviewed. Moreover, similarities exist between the new generation of large High Energy Physics experiments and accelerator control. Also the vast experience in software for accelerator control is more and more useful for the physics experimentalists.

1. Introduction

1.1 The accelerator controls problem

Various types of accelerators exist. One of the simplest is the Electrostatic Van der Graff and one of the most complex is the CERN cascade of 12 accelerators running in multi–user mode. The classes of accelerators are : DC machines (electrostatic, pseudo DC (cyclotron), pulsed machines (Linac/ Synchrotron), mixed (circular collider)).

1.2 The components of accelerators

The general (machine) components are the magnets, cryogenic supplies, RF plants, vacuum, instrumentation and beam diagnostic, ions or leptons sources, safety and services (cooling, ventilation, etc). Other components, from the controls point of view, are power converters (power supplies), timing, synchronization, sequencing, mechanical movement, measurement instruments, and simple ON–OFF elements.

1.3 The function (or the duty) of controls

The main function is to maintain the running condition of the equipment. Controls are also interfacing with the operators and users of the accelerator. The data acquisition and data recording is done by controls. The different types of actions are the setting up, running down, modifications of working conditions, help in survey and trouble–shooting, studies and improvement of accelerators, recovery after fault repair, adjustment and optimization of working points and production.

1.4 The domain of the controls

The controls domain reaches from the operators to the accelerator equipment through various stages, where the separation line between the equipment and the controls is not always very well defined. Commercial equipment including its own control is used as well as locally embedded data treatment and the merging of analog and digital electronics.

1.5 The scope of the lecture

Not included in this lecture is the control theory about close loop control and optimum control nor the finite state machine theory or the signal treatment.

On the other hand, the controls problems, with various view points are treated as well as the computer science techniques used to solve controls problems, the trends of evolution of the control techniques and future possibilities. There will also be a short explanation of the hardware interface with equipment. The lecture was mainly architecture and software oriented.

2. Accelerators and their controls

2.1 Classes of equipment

The classes of equipment are the simple ON/OFF acquisition or the acquisition and control, (e.g. state of relay; the complex digital equipment, the analog (or quasi analog) systems, the multi−states and hybrid (e.g. power converter); the timing system and instrumentation (a mixture of timing, analog and digital control with sequencing).

2.2 Actions to be performed

These actions are the setting up and running in, the running down and stopping, the adjustment and optimization of the working condition, the survey of the system, recovery after correction of abnormal state, the saving and restoring of the working point, preparation of future runs and operation, studies of accelerator physics, trouble−shooting of hardware and software, modifications and adaptation of existing systems and the introduction of new controls facilities with qualifications and reception tests.

2.3 Users of control systems

The control system is the necessary path between any user and the accelerator equipment. The operation of an accelerator complex requires many specialists in many different disciplines. The specialist wants to see the full details of his operation and the rest must be hidden.

2.3.1 The Equipment Specialist

He constructs and tests independent parts of the equipment and also assembles and integrates these parts. For this, he needs a stand – alone operation, full control of all details of his equipment, an easy way of accessing his control tool set, and widely distributed access points (close to the equipment).

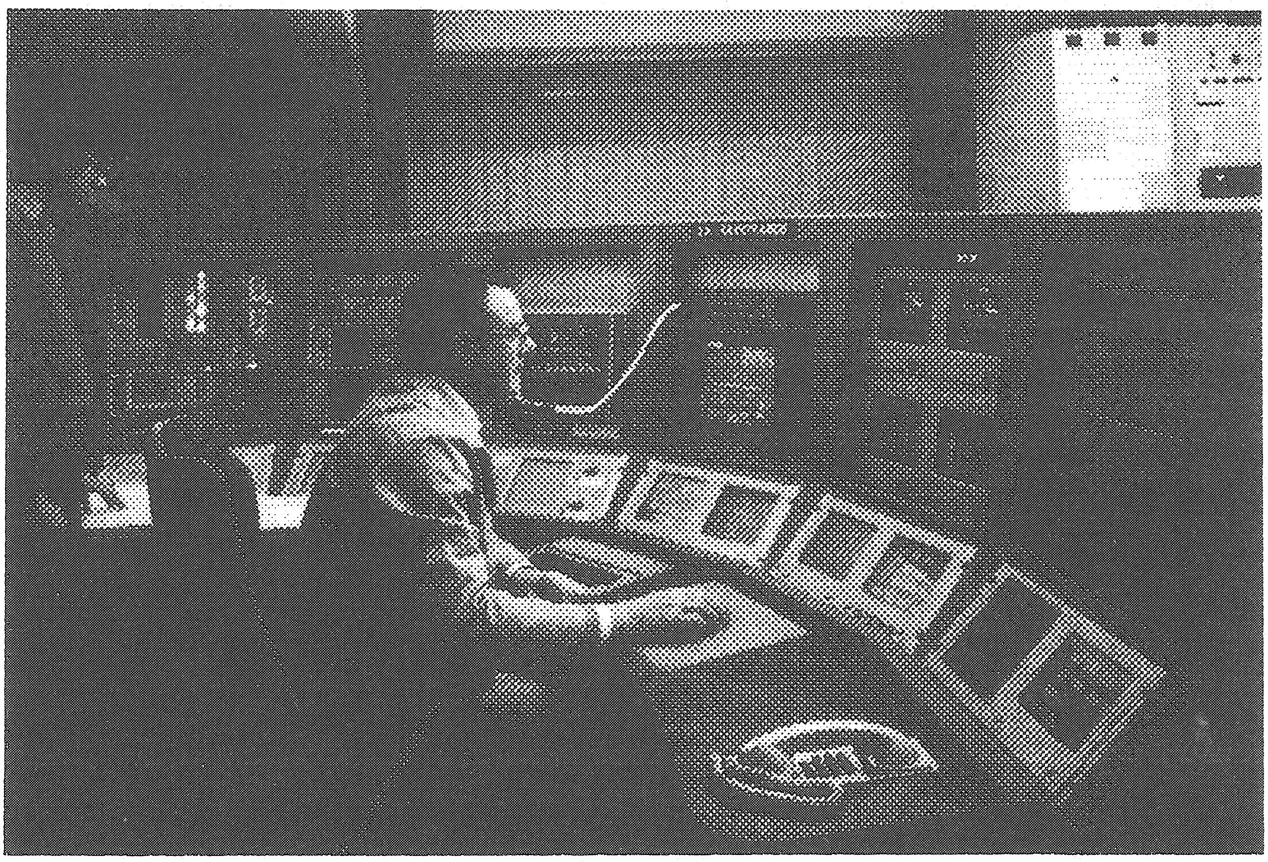
2.3.2 The Accelerator Physicist

He takes the various hardware parts and connects them to form an operation. He is mainly concerned with the interaction of the various facilities and is an intensive user of the instrumentation and beam diagnostic facilities. He explores frontiers of the working condition, requiring very flexible and powerful control facilities. He also requires new controls facilities, as on – line modelling, expert systems, off – line simulation and operation preparation.

2.3.3 The Accelerator Operator

His task is to keep the accelerator complex running for long periods of time. He must also execute the production program as scheduled. The operator requests from the control system convenient ways of monitoring the overall operation. He must be able to diagnose and correct faults and to change parameters and operations as required. His must log information on the current working condition of the accelerator.

The control room and the human interface of the controls system are the working environment of the operators. The ergonomy of the operator desk and the control room is very important.



The CERN PS operator desk

2.3.4 The Physics Experimentalist

The physics experimentalist requires information about the state of the accelerators and their beams, and if there is no conflict with other users or with the accelerator itself, he must to be able to control and correct the elements in the beam lines.

2.3.5 The Maintenance and Repair Team

Generally, this team is a mixture of equipment specialists and controls specialists. They want to run powerful tests quickly and use diagnostic facilities. They also use on – line documentation and help procedures. They must have a good overview of the controls system and also good relations with the operators.

2.3.6 The Control Developer

He uses tools for introducing new controls facilities and also for tests, debugging, and validation without disturbing the accelerators' running conditions. The controls developer wants good management facilities for the software components.

3. General control architecture

The use of a controls system model is an efficient way of reducing the complexity of the system. It also gives a good overview of the problem concerned and it is a starting point for a formal description. Starting discussions between partners (clients and developers) can also be done very effectively with this model.

Two models are shown here: the model of the 3 functional layers and the data flow model.

3.1 The model of 3 function layers

The model of the 3 function layers provides the connecting path between the operator and the equipment, and also the environment for running autonomous activities. It offers connection to the other digital data processing facilities, e.g. office workstations, central D.P.s , etc.

3.1.1 The top level: operator/human interface

The operator is the master of the control activities. He needs good information on the states and actions taken by automatic process. The operators has multiple view points of the process for correlation of process events and for better understanding of process phenomena.

The properties of the layer of operator interface are :

- pure asynchronous processing (interaction of operators);

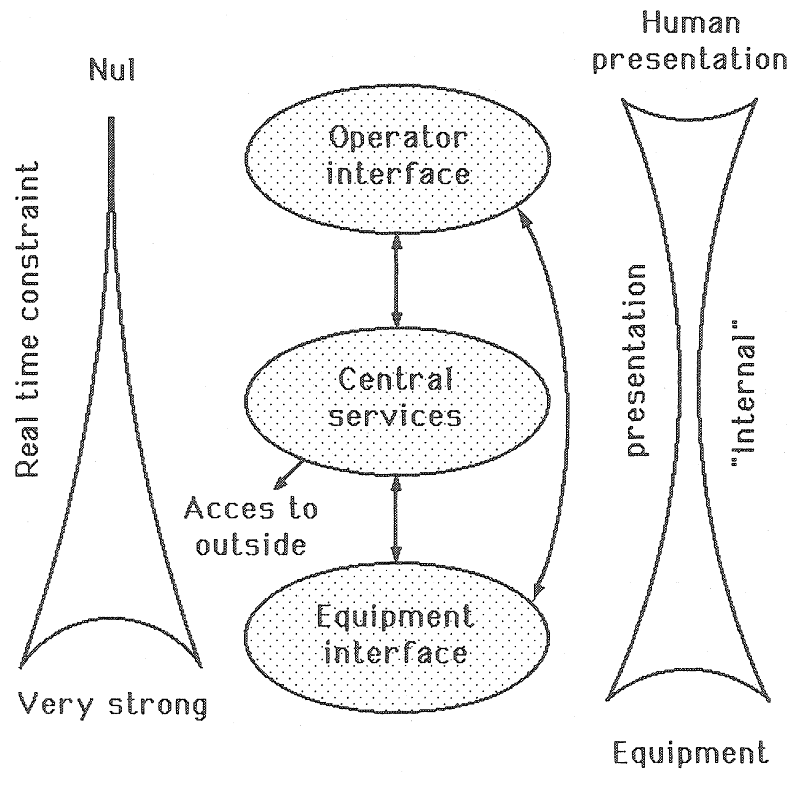
- user interface must be very attractive, user – friendly and easy to learn;
- high resilience to operator mistakes and random actions;
- capable to present very large quantities of data in a wide diversity of formats (texts, graphics, synoptics, etc.).

3.1.2 The service layer

It provides services not dedicated to a special process and offers the general data processing service. This layer is the environment for autonomous processing and tasks.

The properties of the service layer are :

- fast response time to a query or request;
- high level reliability and availability;
- transparency for the user (operators) as much as possible;
- easy to update, maintain and service by control operation and developer teams.



The 3 layer model

3.1.3 The equipment layer

This layer provides the connectivity to the process equipment and reacts to equipment stimulus. It does controls according to the equipment time constrains and coordinates the various functions which take part in the controls of the equipment.

The properties of the equipment layer are:

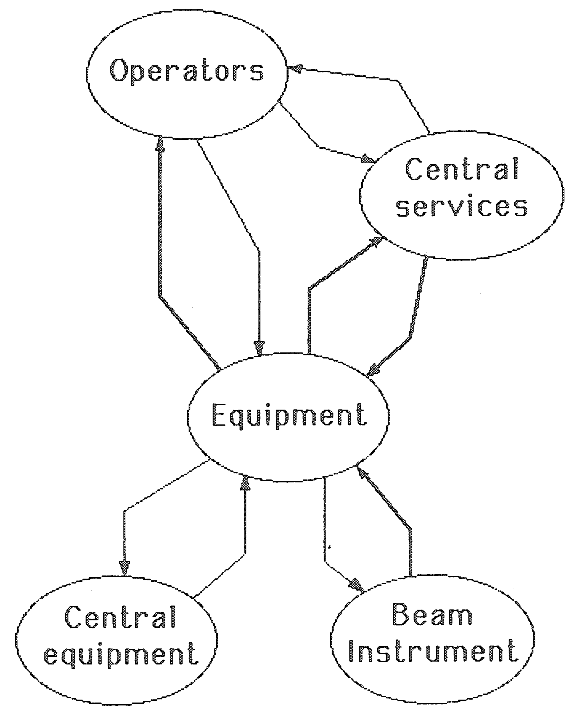
- hard real−time constraints especially for pulsed accelerators;
- the request of very high level of parallelism and distribution in data processing;
- provision of data reduction and data formatting (according to the equipment specification).

3.2 The data flow model

This model consists of three elements, the data sources, the data sink and the data lifetime.

3.2.1 Data sources

The data sources are the equipment acquisition (medium rate), the beam instrumentation (intensive data source), the operators (slow rate), and in the central service: the main coordination (medium rate) and the data base and storage (medium to high flux).



The data flow model

3.2.2 Data sink

The data sink is composed of equipment with medium rate range: PPM equipment (pulse – to – pulse modulation), and other ones with slow rate: for DC machine or none PPM equipment. The operator presentation has a very high flux of data. The central service is a very intensive data sink during some special tasks.

3.2.3 Data lifetime

The data lifetime of the equipment is medium to long (up to 1 run). The operator presentation needs a very short time and is always volatile, while the central service has a very long lifetime (up to the lifetime of control systems). The central service always makes a hard copy and back – up copies.

4. Equipment access (front – end processing)

The complexity of this layer depends very much on the "dynamic" of the accelerator.

There are very drastic differences between

- the DC or quasi DC machines;
- the accelerators with intensive PPM mode;
- the multi – path beam transfer line.

One of the functions of this layer is to relax the real – time constraints. Furthermore, the merging between synchronous and asynchronous actions, maintaining the running conditions (especially in PPM mode), synchronizing the control actions as well as running the highly repetitive process are some of the more important functions. The morphology can be described as a high level of parallelism in processing with a very time – sensitive process.

4.1 Visibility from the higher layer

The goal is to provide a uniform access method for the equipment. The benefits are a uniform and homogeneous documentation, easy writing of data – driven general programs, simplification of the network function needed, and a well defined and stable interface between the layers.

4.1.1 Possible solutions

One of the solutions is the data base approach, which will have data base access to save and retrieve data records. It will also have functions acting on these records to execute predefined actions on the equipment. Another solution is the object – oriented approach, giving direct access to the equipment by its name with an action key (selector).

4.1.1.1 Data base approach

This approach can easily be provided, especially for small and simple systems. All data of an equipment will be directly accessible and special cases can easily be implemented. The process for archiving/retrieving and starting – up after an emergency is simple and efficient.

There are also drawbacks in this approach. The structure of the data record is imported in application programs and there is a large number of access functions to the various record elements. This approach also allows any half – baked and "spaghetti" type of application programs. The long – term maintenance of application software can be very difficult and access to the data base can be a bottleneck of the system.

4.1.1.2 Object – oriented approach

The benefits of this approach are the very well controlled access to the equipment and the very uniform general services provided by inheritance mechanism. This approach allows any number (in principle) of abstractions with data hiding. The application programs are not sensitive to the implementation of the equipment access method (easier maintenance). The approach is very well adapted to distributed systems.

The drawbacks are the difficulty for general services like archives, retrieving of data, etc. A special property for a special case must be implemented in the object. This approach requires a new way of thinking, especially for the "Fortran" programmers.

4.2 Real – time processing

The goal is to handle the Real – time problem of controls. The benefits are that this real – time processing releases other program layers from real – time constraints, and the time sensitive programs are concentrated around the equipment itself. It also allows reduction of the number of various mechanisms to solve the RT problem.

The method to build this processing consists of reducing the complexity of the problems by analysis and modification of external specifications and also minimizes the number of significant events issued by the equipment. The method requests also to define standard behaviour of the various classes of equipment (standard control protocol of equipment) and to use a unique repetitive running mode.

4.2.1 Possible solutions

One solution consists of the model of the 3 synchronous actors, for the preparation task, the control action (send data to the equipment), the acquisition process (retrieve results of measurements and status of equipment). These 3 actors are executed in a synchronous and recursive manner (the basic period concept).

4.2.1.1 Preparation task

The preparation task prepares all the data structures and values for the coming controls and acquisitions tasks. At the time of the significant event, which triggers the action, all the external conditions and parameter values for the basic period must be defined and no more changes can be executed later on (for the basic period). For this task, the RT constraint is normally not too strong (time window for this activity is not too tight).

4.2.1.2 Control task

The control task is sending the raw data (built by the preparation task) to the equipment. The time window for this action can be very narrow. Errors or problems to access the equipment must be reported. In special cases, more than one task can do the job, especially when more than one time window is needed to execute control of the equipment during the basic period.

4.2.1.3 Acquisition task

It reads the equipment data from the equipment according to data structure provided by the preparation task. This task also transforms raw acquired data into equipment data with possible data reduction and sends this data to the equipment object. When all data are available, it sends events to data consumer tasks. For instrumentation, the quantity of data to be acquired can be large.

4.3 Data source processor

The goal is to provide a regular data source mechanism (during the schedule of the basic period) to various end users in the upper layers. This processor uses an automatic mechanism for acquiring data and application programs driven by pure data flow.

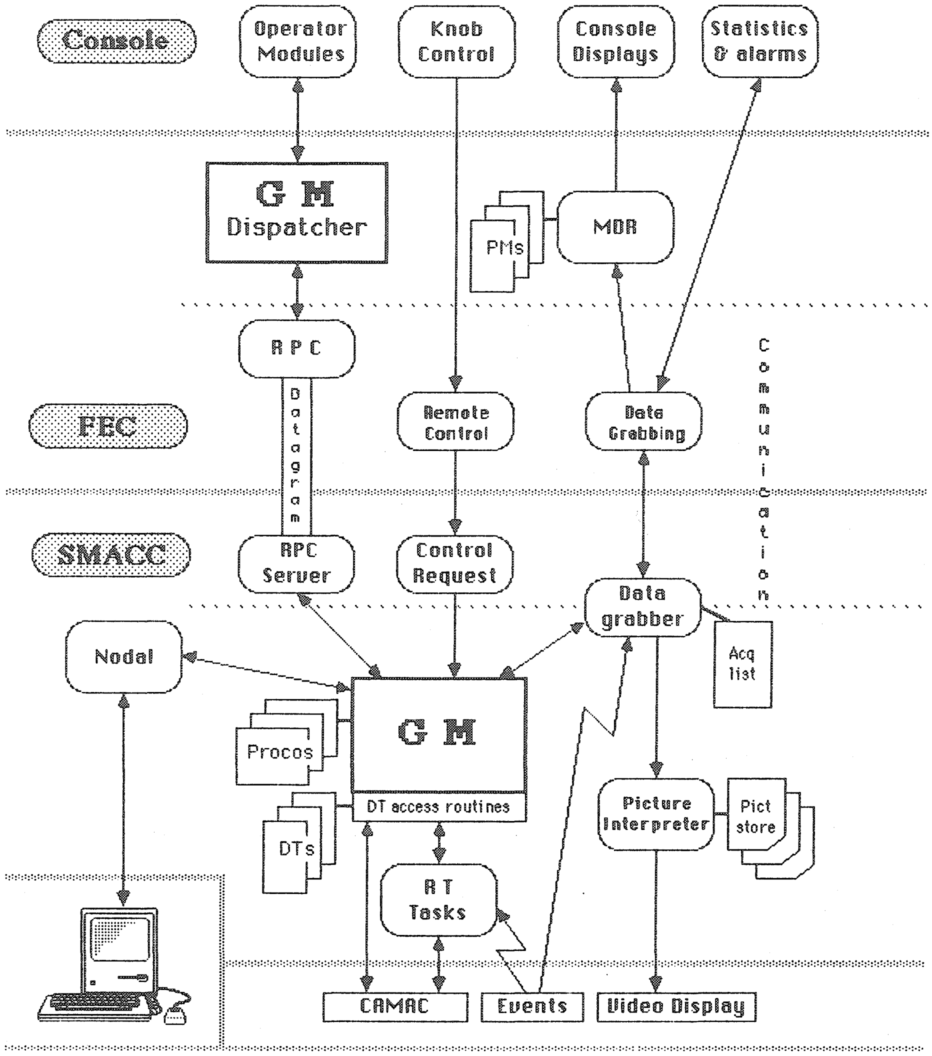
4.3.1 Possible solution

One solution is to send systematically all acquired data. This is a very simple mechanism but only feasible for small or even very small control systems. Another solution is the subscription mechanism, i.e. end user programs (data consumer programs) take out a subscription to a defined data acquisition list. This solution uses difficult list management mechanisms and a tricky process in case of abnormal ending of user programs. It needs an evaluation of the peak condition case and requests dynamic routing and broadcasting process from the medium layer.

4.3.2 Difficulties of the equipment layer

These difficulties are the result of the large distribution (large numbers) of processors (keeping the hardware cost to a reasonable limit and minimizing the hardware overhead). There is also a high degree of parallelism in processing and stringent time dependence (small time window) as well as a very high level of reliability requested. The reliability of control systems depends very much on this layer. As a consequence, a good selection of building blocks is necessary for both hardware and software as well as a good and efficient RT environment. A powerful software and system debugging is requested with RT correlations, parallelism and remote debugging.

Some maintenance difficulties exist. The modification and update of running software request a software quality and certification (need of simulation environment for software qualification) and trouble – shooting tools, which can be very tricky. Trouble shooting and error reporting must be taken seriously right from the beginning of the design.



Example of equipement layer architecture

5. Service layer

The functions of this layer can be well distributed around the other layers according to the computer network properties. The evolution for the implementation of this layer may be very drastic in future, with the new computer technology and networking facilities.

The two main classes of functions are (i) general services to the control activities, (ii) functions which are related to the topology of the control system.

5.1 General services

These are services which can be requested by any part of the control system. They consist of a data base management service, archive and history service, paper output (printer and plotter services) logging, network bridge to other LAN of the laboratory or to WAN, number crunching facility, program librarian and files server.

5.2 Functions of the in – between layer

These are services or functions needed on the path of data between the front – end and the operator interface. They are alarms and survey processing, error reporting and tracing, processing coordination, general manager of controls activity, data concentration and data distribution/broadcasting, network management and data server.

5.3 Major components of the service layer

5.3.1 Data base

Ideally, it will supply data to all data driven programs, in conjunction with the 2 other sources of data: equipment and operators. Its properties are to fulfil the RT constraints, to respond in a predefined and "short" time, and to provide uniform and efficient access methods. Data must be secured and data integrity guaranteed for the reliability of the control system.

The main classes of data structures are the dictionary tables (name to record), the lists (sequence of records with links), the indexes (to flat files or flat collections of data objects).

5.3.1.1 Possible implementation

The RT data base service is used for implementation. The RT data base can easily be derived from one central data base (off – line data base) for the stable data. The updating (plus pretty printing,backup..) is well provided for by the central DBM. There is a general service for multi – viewpoint of RT data base with a uniform access method. All data structure is easy to manage and maintain.

The ad – hoc solution for specific domains gives more flexibility for the specific problems of the domain. The implementation for the first domain is fast but the data is difficult to manage and maintain. No general service exists. The access method to the data is domain dependent.

Experience has shown that the RT data base has decisive advantages for large control systems.

5.3.2 Archive and history service

This is an intensive user of the RT data base. It must provide service for archiving and retrieving typical accelerator working status, for deferred (off – line) data analysis, setting – up of the machine from the power – off state, and for off – line preparation of the future machine state.

5.3.3 Alarm system and survey processors

These systems do an autonomous monitoring of the equipment. They inform the operators of abnormal status, and issue warning information and global beam monitoring data. Major properties requested by the users are reliability of alarms information, very high availability of the alarm system, fast response time (from an error in the equipment to the message in front of the operator), simple interaction facility, significant messages (not encoded). Through these properties the operators will reach a high level of confidence in working with the alarm system. If this high level of confidence is not reached, the system will never be used afterwards.

The alarm system is a large user of the data base service. The data base provides easy modification according to equipment evolution, good maintenance and updating tools, attached correcting procedure, standard and well–defined, and homogeneous and significant messages.

5.3.3.1 Major components of the alarm system

The equipment monitoring process surveys accelerator equipment and controls system components and detects abnormal states. It also reports the detected faults to the alarm collecting central service. The alarm collecting service receives alarm messages from the monitoring process and possible other application packages. It maintains the equipment status list and prepares the display list for the operator consoles. It also acts according to the operator interactions, on the equipment or on the list.

The console presentation and interaction process displays the current accelerators status in a condensed form or in a detailed form with various levels of details. This process interacts with the operator for access to various levels of detailed information and for modification of the central equipment list (masking an equipment not in use, releasing a surveillance constraint).

5.3.3.2 Possible implementation

This can be distributed survey processing as well as centralized alarm collecting. Also used is distributed (on the operator console) presentation and interaction processing. Equipment access must provide elaborate and standard status information.

5.3.3.3 Problems

The end user (operators) must get confident very quickly with the system. This confidence must be maintained during the entire lifetime of the controls system. There will always be difficulties in detecting the abnormal state. This is not too difficult in finite state equipment but can be very difficult for analog values, for very dynamic or wave form signals. Other difficulties are how to define (and by whom) a reference state of equipment complex and how to cope with the unavoidable "very special equipment behaviour". Moreover, it is certainly not easy to work with the very large number of equipment and equipment classes and to provide enough standard, as well as simple and well defined recovery mechanism.

5.3.3.4 Actions to be taken

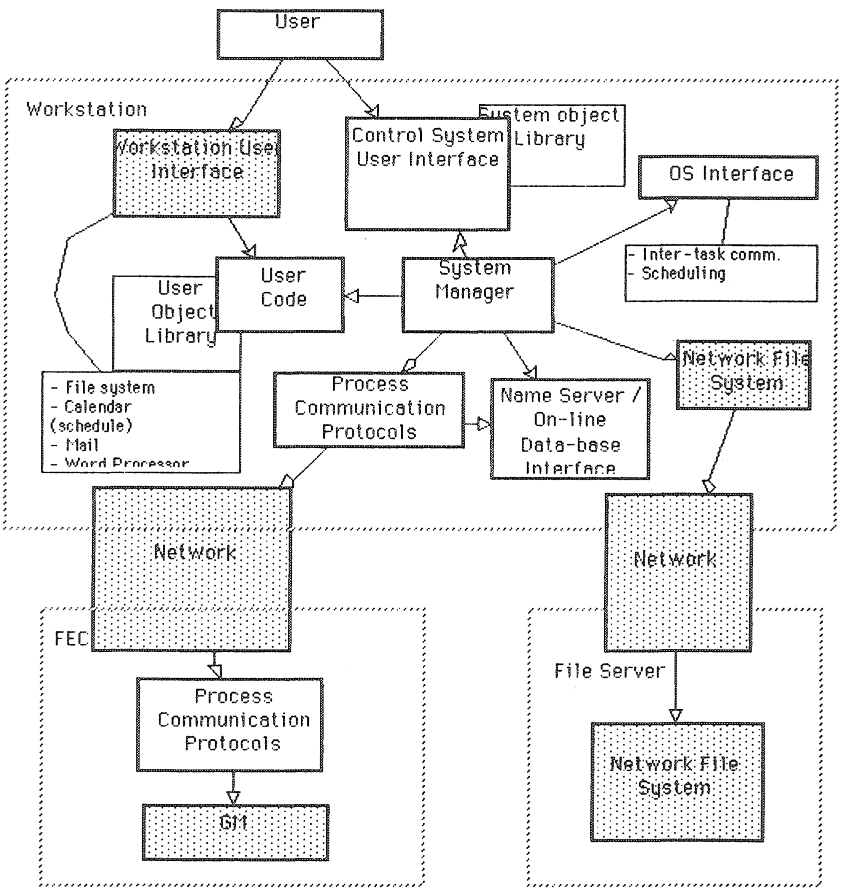
It is important to integrate the problem of the alarm system from the beginning of the project, and to strengthen the equipment as much as possible (hardware and associated software) to follow standard behaviour and meaning for status information and simple recovery procedures. It is also necessary to use the finite state machine model for the equipment and to define early in the project the alarm messages, their real meaning, and standard procedure for recovery.

6. The operator interface layer

This layer provides the human interface to the accelerators through the control system. Its quality and its user–friendliness will largely contribute to the success of the control system. The office and home computers, easy to use, low in cost and to be learned quickly, represent a big challenge to control systems and their developers The fast evolution of the technology (hardware and software) in the fields of graphic workstations, with graphic and interaction software tools and standards, are a real opportunity to have an efficient and attractive operator interface. The user does not want to be cut down by the controls system (= operator interface) in his phantasy for running the accelerators.

6.1 Function of this layer

In order to provide an efficient human interface, the layer must have several functions. One of these functions is to reduce the complexity of the accelerator process, and present various levels of abstractions in the presentation and to structure this presentation. It also must give easy and uniform access to any of the nucleus equipment elements of the accelerator complex. Another function is to provide a very abstract view of the process (beam physics view point) and global operation. Also important is the uniform error reporting with not ambiguous message presentation.



Example of operator interface layer

6.2 Properties of the implementation

They must be attractive for the user (operators and developers), and easy to maintain, fast for adaptations and modifications according to equipment and accelerator processing evolution. There must be a simple "programming" environment, easy to learn and to use by the various partners who contribute in developing applications. The operator interface will benefit from the rapid and enormous progress in the domain of computer – human interface. Specifications have to be very well understood and must give a powerful context of discussion between the partners (user and developers). On – line documentation must be provided automatically to the maintenance team for trouble – shooting.

6.3 Technical solutions

The current trend is to use graphical workstations or first class office computers (no more aggregates of computer peripherals), and to rely more on industrial software and international standards.

Reduction of complexity can be obtained by structured presentation, i.e. through global to detailed views (tree structure). The synoptic presentation is very attractive and user – friendly. There is a request of many graphic resources (data base with graphic data structure, and powerful graphic editor). The "virtual accelerator" for multi – pulse machines (PPM mode) gives an independent view for every kind of beam and reduces the coupling constraint of the equipment.

Simple equipment access can be done by general tools: knobs and panels of action buttons. Other tools for more complex cases are the data viewer facility, 2 dimensional or 3 dimensional representation running in repetitive mode (driven by the data flow), and synoptic "animation" with status, data, simple graphic, etc.

Another need is the good and easy programming environment with multi – processing, multi – windows, with a process manager (including resource manager) for console supervision, simplified graphics and interaction environment tuned to process. Simple programming is achieved, with interpreter including network facility (ex – NODAL), network compiler for compiled language, simple and uniform access to equipment data (object – oriented, data server).

6.4 Dedicated tools for maintenance

For the maintenance team and debugging phase, access to hidden data and main internal data flow is required. This is obtained by interactive access through the interpreter language, visibility of the list of equipment in use, validation procedure suite for reception and trouble – shooting, and a facility for data path tracing.

7. General problems of control systems

Certain general problems must be solved. This will be either explicitly chosen after evaluation, implicitly worked out by the facts and the history.

7.1 *Security and access control*

Here two problems must be solved. First, the users filtering for anti–hacker protection and the access to equipment or processes, only to people authorized. The solution is done by classical methods: absolutely no external access to the system, a non–popular environment (not UNIX or VMS), user identification and recognition. Secondly, the mutually exclusive access to equipment. Normally, the access to the accelerator process (equipment) can be made by one person only at a time (for controls). Consequently, access to controls must be mutually exclusive between the various simultaneous users. This protection can be done by offering only one access point to one equipment; by discussion between the operators in the control room; by reservation of nucleus equipment (semaphore mechanism); by exclusive split of the equipment between mutually exclusive working sets and access controlled by the general manager.

7.2 *Analog observation system*

This is needed to look at the raw waveform of power supplies, beam observation instruments and timing pulses. It must provide time correlation between various signals. It is very dependent on the hardware and must be very reliable as it is the last facility available for the operators when the control system is down.

7.3 *Applications development policy*

The applications are the main domain of evolution, modification and innovation during the lifetime of the controls system.

The two extreme types of applications are (i) a well–defined and stable control procedure, and (ii) the 5 minute program for a quick experiment with the accelerator beam. These extreme cases can imply well managed applications development with education, SASD, validation and documentation or a "do it yourself" application using building blocks and tools kit.

The applications can be developed either by a dedicated, well educated and indoctrinated team, where applications are well manageable, and the administration is very bureaucratic. In this case, the end–user can be unhappy, as he does not receive what he has expected. The applications can also be developed by the end–users themselves (operation, machine physicist teams) or the equipment specialists. It is then much more difficult to maintain these collections of software modules and to get a fast response time for modification. The user is always happy with his own product, but not necessarily the other users.

7.4 *The lifetime of controls systems*

The lifetime of large accelerators (not the prototype nor the test facility for accelerator research) is today bigger than 10 to 15 years. Typically, 20 to 30 years (or more). The lifetime of one generation of controls systems is around 10 years, for interface equipment it is 5 to 10 years. The lifetime of software modules can be counted with about 5 years, the one of process computers and peripherals with less than 5 years. All these figures imply that the controls system is in constant modification and that the happy situation of starting from scratch is very unusual.

Normally, one is confronted with compatibility problems, transition periods and phases, with difficulties of retrofitting the new facilities and last but not least the intolerable statement (of the young dynamic developers): "the option was chosen for historical reasons".

8. Hardware for control systems

The hardware depends very much on the computing and electronic "culture" of the laboratory. The current trends decrease needs for special equipment with the new products of the manufacturers, and encourage the use of standard (manufactured) equipment for process computers, workstations, computer network, bus for local or embedded systems, and on – board computers and I/O. Special systems are needed for time and events distribution, the analog signal distribution system and the low cost arbitrary waveform generator.

Key features for hardware are the intensive use of standard electronic equipment (I/O boards, buses, embedded computer) and standardization of local mecano.

9. Domains of research and development

9.1 *Modeling*

Modeling is used since a long time but more in off – line mode. The computing power of the new workstation and mini/micro processor allows the use on – line of large and powerful simulation programs. The programs in use are accelerator design programs (lattice computation and optimization programs (close orbit correction).

9.2 *Expert systems*

Embedded expert systems are appearing in control systems. They will be used for trouble – shooting, operator help and beam or accelerator optimization. There are two ways of development of these systems. One is the dedicated expert system for a very limited domain, built directly with the fourth generation language and small rules and facts base; the other one is a large expert system built around the generator of the expert system with a very large knowledge base (partially derived from the control system's data base). The connection with the controls system is done by message exchange.

The main difficulty here is to extract from the various experts (accelerator, equipment, control, operation) their knowledge and to translate it into expert system representation. The long term research for these expert systems is the automatic learning system.

9.3 *Applications generator facility*

One attractive approach is the "spreadsheet" model. It means programming by the end – user without language (no grammar), and without installation procedure. It includes acquisition and control, algorithmic correlation and human presentation. It is a way to converge with the office automation computing.

9.4 *Control Protocols*

Their goals are to define stable control communication protocols between controls systems and equipment, and standard behaviour of the equipment. They are mainly applicable to power converters and instrumentation.

Bibliography

1. F. Beck and M. Gormley, Computer Control of large Accelerators, Design Concepts and Methods, FERMILAB – Conf – 84/43, 0121.220.

2. W.K. Dawson, R.W. Dobinson, D.P. Gurd and Ch. Serre, A Conceptual Design for the TRIUMF KAON Factory Control System, TRI – 87 – 1, 1987, TRIUMF, Vancouver, Canada.

3. B. Kuiper, Controls for Particle Accelerators, CERN/PS/CO/Note 86 – 21.

4. G.P. Benincasa, The PS Control System, CERN/PS/CO/Note 86 – 28.

5. P.G. Innocenti, The LEP Control System, CERN/SPS/87 – 41 (ACC).

6. B. Kuiper for the PS Controls Group, Controls for the LEP Preinjector, CERN/PS/85 – 21 (CO).

7. G.P. Benincasa, First Ideas on the Control System for EHF (European Hadron Facility), PS/CO/Note 86 – 30.

8. The PS Staff, presented by R. Billinge, The CERN PS Complex: a Multi – purpose Particle Source, CERN/PS/83 – 26

9. J. Altaber, P.G. Innocenti and R. Rausch, Multi – microprocessor Architecture for the LEP Storage Ring Controls, CERN/SPS/85 – 28 (ACC).

10. G. Shering, Consoles and Displays for Accelerator Operation, CERN SPS/83 – 35 (ACC).

11. F. Perriollat, A. Gagnaire, R. Debordes, The Main Operator Consoles for the PS Accelerator, CERN/PS/85 – 22 (CO).

12. G. Shering, User – friendly Process Control, CERN/PS/85 – 52 (CO).

13. F. Di Maio, W. Heinze, F. Perriollat, Experience with the Use of "Macintrotte" for Commissioning Process Equipment of the LEP Prein – jector, Proc. IEE Part. Acc. Conf, Washington, March 1987, pp.597 – 600.

14. L. Merard, Th. Pettersson, Ch. Serre, Concurrent Execution of Real – time Displays, PS/CO/WP 83 – 78.

15. W.F. Herr, R.J. Lauckner, C.G. Saltmarsh, Design Principles of the High Level Controls Structure for the CERN SPS, CERN/SPS/87 – 40 (AMS).

16. M. Chanel, Th. Pettersson, The LEAR control system – Phase II, Proc. of the 2nd International Workshop on Accelerator Control Systems, Los Alamos, October 1985, pp. 146 – 152.

17. J Poole, Using Oracle Databases in a Particle Accelerator Control System, LEP Controls Note 68, 24.4.1986

18. J.H. Cuperus, The Database for Accelerator Control in the CERN PS Complex, CERN/PS/87 – 32 (CO).

19. L. Normann, A. Spinks, Recent Experience with C – Tree, A Data Management System, CERN/SPS/AOP/Note 87 – 15.

20. J.H. Cuperus, An Interactive Alarm System for the CERN PS Accelerator Complex, CERN/PS/CO/83 – 8.

21. R. Bailey, J. Ulander, I. Wilkie, The new Applications Software for the CERN Super Proton Synchrotron, CERN/SPS/AOP/Note 87 – 13.

22. A. Daneels, E. Malandain, M. Martini and P. Skarek, Standard Software Modules for Equipment and Composite Variable Control, CERN/PS/CO/WP 83 – 77

23. G.P. Benincasa et al, Modulation of the LEPTON Production for the CERN LEP Preinjector, CERN/PS/88 – 36 (CO – LPI).

24. P. Heymans and J. Lewis, The Program Line Sequencer, a new Approach, CERN/PS/87 – 34 (CO).

25. R. Giachino, J. Miles, A. Spinks, Contention Resolution in a Distributed Control System, CERN/SPS/AOP/Note 87 – 12.

26. M.C. Crowley – Milling and G.C. Shering, The NODAL System for the SPS, CERN 78 – 07, yellow report.

27. B.E. Carpenter, R. Cailliau, G. Cuisinier and W. Remmer, System Software of the CERN Proton Synchrotron Control System, CERN 84 – 16, yellow report.

28. J.P. Delahaye, H. Kugler, A. Levy – Mandel, F. Perriollat and J.P. Potier, On – line Modeling, a Tool at Commissioning of the 600 MeV e + e – Accumulator (EPA) of LEP, CERN/PS/87 – 18 (CO/LPI).

29. E. Malandain and P. Skarek, An Expert System for Accelerator Fault Diagnosis, CERN/PS/87 – 33 (OP/CO).

30. E. Malandain, S. Pasinelli, P. Skarek, Knowledge Engineering Methods for Accelerator Operation, CERN/PS/88 – 35 (OP – CO).

31. A. Burns, J. Menu, DIALOG: a System for Instrumentation Diagnosis, CERN/SPS/88 – 21 (ABM).

32. C.G. Beetham, R.J. Lauckner and C. Saltmarsh, Overview of the SPS/LEP Fast Broadcast Message Timing System, CERN/SPS/87 – 21 (ACC).

33. R. Rausch, Real – time Control Networks for the LEP and SPS Accelerators, CERN/SPS/87 – 35 (ACC).

34. G.P. Benincasa, A. Daneels, P. Heymans, Ch. Serre, Engineering a Large Application Software Project: the Controls of the CERN PS Accelerator Complex, CERN/PS/85 – 20 (CO).

35. G.P. Benincasa, A. Daneels, P. Heymans, Ch. Serre, Estimating the Development Effort for a Large Process Controls Application Software Project, CERN/PS/CO/WP 83 – 80.

36. R. Bailey, J. Ulander, I. Wilkie, Experience with using the SASD Methodology for Production of Accelerator Control Software, CERN/SPS/AOP/Note 87 – 16