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24.1.1984

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D. Heagerty, P. Heymans, J. Kenaghan, Ch. Serre

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CM-P00059338

Paper to be presented at the IX. Triennial World Congress
of the International Federation of Automatic Control
IFAC, Budapest, July 2 - 6, 1984.

INTERACTIVE CONTROL OF THE CERN PROTON SYNCHROTRON COMPLEX

D. Heagerty, P. Heymans, J. Kenaghan and Ch. Serre

PS Division, European Organisation for Nuclear Research, CERN, CH-1211 Geneva 23, Switzerland

Abstract. The computer-based control system for the CPS (CERN Proton Synchrotron) complex of accelerators, is manipulated by a team of operators, via a group of identical, "general-purpose" consoles, each with its own dedicated computer. Any application program may be selected at any console through a tree of menus, which is structured in such a way that the branches of the tree correspond to different parts of the different accelerators. At a certain point in the path down the tree, the appropriate set of control parameters is reserved by the console for its exclusive use. The allocation of control parameters to consoles is thus completely dynamic. The console's interactive devices are also dynamically allocated to the various application programs running concurrently on the console computer. In particular, the so-called "Knobs" may be dynamically "attached" to control parameters, thus allowing manual adjustment of individual parameters.

Keywords. Computer control; interactive control; minicomputers; process control.

1. INTRODUCTION

The CERN Proton Synchrotron (CPS) complex of particle accelerators provides particle beams of various types to different experiments and to other accelerators (Fig. 1). This group of accelerators has a control system that is based on a network of minicomputers. The accelerators have a basic "cycle" of injection, acceleration and ejection, that takes about one second, including some "dead" time when the control parameters may be changed or acquired before the next cycle starts. The beam can be programmed to go to different destinations in successive cycles (Boillot, 1981).

Legend:

AA : Antiproton Accumulator	PS : Proton Synchrotron
ATP: Antiproton Transfer to PS	PSB: Proton Synchrotron Booster
FTI: Primary Beam Transfer to ISR	PTS: PS Transfer to SPS
LINAC: Linear Accelerator	

Fig. 1. CERN 28 GeV Accelerator Complex.

The accelerator operators, working at a group of consoles, have two different means of dynamically adjusting the control parameters. At each console an operator can:

(i) run application programs, which may either go through a pre-defined sequence of controls, or else interact with the operator - in either case a number of parameters may be adjusted together;

and

(ii) "attach" control parameters to the "Knobs", in order to make manual adjustments.

This paper describes the software that has been implemented to allow these two modes of control.

It should be understood that what is described here is only a part of the control system. In addition to the "control" facilities described, there are, for example, facilities for display of parameter values and equipment status, not to mention the independent alarms and surveillance systems.

In order to put this part into perspective, section 2 describes some important aspects of the "environment" and its implementation.

Section 3 then presents "Maître", the software that interacts with the operator to allow him to select application programs for execution.

Section 4 describes the allocation of the console's interactive devices to application programs, and, in particular, the Knob system.

2. THE ENVIRONMENT

At present, the CPS Control System provides the operation team with a group of five identical consoles, situated in the CPS "Main Control Room" (MCR) (Fig. 2). The consoles interface to a "star" network of minicomputers.

The computers may be split into three categories:

- (a) the console computers
- (b) the FECs (Front-End Computers), that control the accelerator hardware,
- (c) "general services" computers.

Fig. 2. The CPS Main Control Room

The overall structure, and distribution, of the control system software is necessarily dependent on the layout of the computer network, as well as on the system's operational requirements.

2.1 The Computer Network

Each console has a dedicated computer. These "console computers", together with the FECs (Front-End Computers) and "general services" computers, form a star network (Fig. 3).

Fig. 3. Topology of the computer network

Some of the more important "general services" computers are :

- (a) the Message-Handling Computer (MHC), which is at the centre of the star and performs the task of packet-switching;
- (b) the Program-DEvelopment computer ("PRDEV");
- (c) the "TREES": this computer holds a number of important databases, plus the necessary access routines, as well as software associated with, for example, the Alarms System.

The computers are located centrally near the MCR; the accelerator equipment (up to 500 meters away) is controlled by the FECs through a CAMAC transmission system. Local intelligence is situated near the equipment in microprocessors, which take some of the load off the FEC itself.

2.2 The Consoles

Each of the five consoles provides the capability of controlling the set of parameters corresponding to any part of any accelerator of the CPS complex.

Fig. 4. A console

The console (Fig. 4) is divided into four main sections, each section containing its own interactive devices and display screens. The use of these sections is as follows:

- (a) the selection and display of analogue signals on two oscilloscopes;
- (b) the selection and display of video signals on four small black-and-white TV monitors;
- (c) the display, on a colour screen, of "alarm" or warning messages;
- (d) the control and display of the values of the control parameters, by means of the interactive devices and the graphics and display screens.

This last section constitutes, in fact, the main man-machine interface for normal operation, and can itself be regarded as having two parts:

- (a) the Main Touch Panel, at which application programs are selected from a tree-structured set of menus;
- (b) the Interactive Tools, which are dynamically allocated to application programs - User Touch Panel, tracker-ball, keyboard and Knobs.

The Knobs constitute a special case, in so far as they have two different uses: they may either be "allocated" to application programs, or be "attached" to control parameters. This second case is described in detail in section 4.

2.3 Structure of Application Software

The application software is distributed over the network, so that any given "program" is split into two or more modules, each on a different computer. The structure of the software thus reflects the structure of the network, though at the same time it must satisfy operational requirements for both the man-machine interface and the control of the accelerators (see Fig. 5).

- (a) In the console computer, we have the "Operator Modules", which interact with the operator and send requests to the appropriate software module(s) in the appropriate FEC.
- (b) In the FEC, the "Process Modules" are executed on request from the Operator Modules. They synchronise with the repetitive cycle of the accelerator, and send on, to the next layer of software, a sequence of requests for control of the accelerator equipment. In many cases, once the Process Module has been started, the Operator Module has nothing more to do, and stops, thus liberating whatever Interactive Tools it may have been using on the console.
- (c) The control of an "equipment" is performed by an "Equipment Module" (EM). One Equipment Module for each type of equipment (e.g. power supply, RF cavity, vacuum pump, and so on), and may be used by different Process Modules concurrently. Some Equipment Modules control equipment directly; others delegate that part of their work to one or more microprocessors.

3. SELECTION AND EXECUTION OF OPERATOR MODULES

3.1 Selection of Operator Modules

Maître presents each menu as a page on the Main Touch Panel (Fig. 6), possible choices appearing

MAIN MAGNET

PLS

GENERAL LINES

GENERAL LINE

DIRECT

SECTION TRANSV

SECTION RECORD

SECTION REC LINE

90 LOAD TIME .4481

Fig. 6. The main touch panel

3.2 The Main Tree

The "HOME" button takes one back up to level 1 of the tree, rather than level 0. The reason for this is that, in practice, we think of the Main Tree as a "forest", the roots of all constituent trees being at level 1. Each tree represents a different mode of operation of the accelerators; e.g. starting up, normal operation, hardware or software specialist access.

The "SUITE" button allows one to move around the pages belonging to a single node. These pages are arranged as a circularly linked list: "SUITE" simply requests Maître to display the next page in the list.

By the time one arrives at a page on level 4, one has defined the accelerator (at level 1), and the exact part of that accelerator (at levels 2 and 3) that one wishes to work on. At level 4 one may choose between the different types of program to be selected for execution (e.g. measurement or control).

3.3 Equipment reservation

Ideally, it should be possible for two (or more) operators working at different consoles, to simultaneously adjust two different accelerators, or even different parts of the same accelerator, without interference. To ensure that the controls being made at different consoles do not conflict, we have a "reservation" scheme for all accelerator equipments, that enables a console to reserve a set of equipment for its exclusive use.

The equipment is partitioned into what we call "Working Sets" (WSET) (which may overlap). When Maitre is asked to descend the Main Tree from level 3 to 4, it automatically reserves the appropriate Working Set of control parameters, so that Operator Modules, called at level 5, will be permitted to control that equipment. Similarly, when going back from level 4 to 3 (or "home" to level 1), the Working Set is released.

There is a one-to-one mapping between level-4 nodes of the Main Tree, and Working Sets. This is because each level-4 node of the tree effectively represents a specific part of an accelerator.

3.4 Starting Operator Modules

The menus presented in the level-5 pages contain the names of Operator Modules to be executed. Pressing one of these buttons is interpreted by Maitre as a request to start the corresponding Operator Module. Several Operator Modules may run concurrently: up to one per Interactive Tool per Operator Module.

3.5 Implementation

In Fig. 8, we can see how Maitre, running in each console computer, interacts with software in the TREES computer and in the FECs, the main components being as follows:

- The List of Active Programs (LAP) is a table of data describing the Operator Modules currently running on the console computer.
- On the TREES computer's disc, the Main Tree database holds the data for all the touch-panel pages of the Main Tree.
- The OM-database, also on the TREES, contains descriptions of all existing Operator Modules, including, for example, the set of Interactive Tools needed during execution.
- The WS-database, again on the TREES disc, holds the data for all Working-Sets: i.e. lists of equipment.
- Finally, on each FEC, there are the programs "Reserve-WS" and "Release-WS", and a set of local copies of Working Sets: one copy for each console.

The chronological sequence of events may be summarised as follows (the numbers correspond to those marked in Fig. 8).

Fig. 8. Maitre: interaction with other software

Descending the main tree

- The operator presses a button on the Main Touch-Panel.
- Maitre reads the appropriate page from the Main Tree database on the TREES computer, and...
- displays it on the touch-panel.

Reservation of equipments

When the operator asks to descend from level 3 to 4, the following actions occur:

- Maitre reads the appropriate Working Set from the WS-database on the TREES computer, and
- writes it to the appropriate Working Set copy on the appropriate FEC.
- Maitre starts the program "Reserve-WS" on the FEC, and waits for it to finish. "Reserve-WS" simply reads the Working Set that was given to it (in step 5), and reserves every equipment in the Working Set, by making a sequence of reservation requests to the relevant Equipment Modules. If any of these reservations cannot be made, the operator is informed. It is then up to him to decide if he still wants to try to run any Operator Modules. In any case, if an Operator Module tries to control an equipment and finds that the equipment is reserved for another console, it simply outputs a message for the operator, and stops.

Execution of operator modules

- When the operator has reached level 5 of the Main Tree, and presses a button, Maitre first reads the data-record describing the selected Operator Module, from the OM-database on the TREES, and...
- copies it into its "List of Active Programs" (LAP).
- Maitre then starts the selected Operator Module. From here on, the Operator Module runs, interacting with the operator.

Release of equipments

When the operator asks to go back to level 3 (or "home"), the following happens:

- Maitre starts the program "Release-WS" on the appropriate FEC. This program is similar to "Reserve-WS", but sends "release" instead of "reserve" requests to the Equipment Modules.

3.6 Execution Speed

Maitre is written in P+, a high-level language similar to ADA, that was devised at CERN specifically for the CPS control system (Cailliau, 1983).

The time taken to obey a button-press (e.g. to load and display a touch panel page) is typically about half a second. The speed is mainly limited by data transfer rates, rather than processing.

4. MANAGEMENT OF THE INTERACTIVE TOOLS

Once the operator has started a number of Operator Modules, these will execute concurrently on the console computer, each using its allotted Interactive Tool(s).

This section describes the allocation of the Interactive Tools and the scheduling system for Operator Modules, and then goes on to describe the Knob system.

4.1 The Interactive Tools

The input devices available to Operator Modules (at each console) are known collectively as the "Interactive Tools". They are as follows:

- (a) The User Touch Panel, upon which an Operator Module may display a menu of possible actions to be performed, or equipment to be controlled, or whatever.
- (b) The tracker ball, which, with its associated validation button, may also be used to make a selection from a menu: in this case, the menu is displayed on any one of the screens of the console: e.g. the graphics screen.
- (c) The keyboard, which is needed in cases where the menu approach is not appropriate: e.g. for entry of predefined values.
- (d) The Knobs: any knob may be attached to a control parameter upon request from an Operator Module; more usually, however, a Knob is selected and attached from within the Main Tree - this case is described in detail in Section 4.4 below.

4.2 Allocation of the Interactive Tools

A restriction, imposed on us by the (manufacturer-supplied) operating system, was that the Interactive Tools had to be statically allocated to a single "process". We therefore implemented a scheduling system for Operator Modules, that effectively reserves all the Interactive Tools for itself, and distributes them to Operator Modules as required.

Therefore, the Operator Modules must declare, in some sense, the Tools they will need during execution. This declaration is static, in the form of a "Tool-set" which is included for each Operator Module in the OM-database. This information is then used in two different ways:

- (a) As we have already seen (section 3.5), when Maitre is asked to start an Operator Module, it copies the relevant data from the OM-database to the List of Active Programs (LAP). Since it is not meaningful to allocate the same Tool to two Operator Modules concurrently, Maitre compares the Tool-set of the program that is to be started with the Tool-sets of the programs already started: this merely involves a scan of the LAP.

The philosophy adopted for such cases of conflict is that the latest request always overrides previous requests. Therefore, Maitre stops any program(s) using the Tool(s) required by the new Operator Module.

- (b) The second use of the Tool-set is for scheduling the Operator Modules, described below.

4.3 The Operator Module Scheduler

Operator Modules need to interact with the operator, and are therefore often in a "waiting" state.

In addition, the operator, while wanting perhaps two or three Operator Modules to be available simultaneously, will interact with them strictly one at a time.

These observations led to the idea of the Operator Module Scheduler (OM-Scheduler). An Operator Module wanting to wait for a request from the operator, must relinquish control to the OM-Scheduler; this amounts to a simple subroutine call. The OM-Scheduler has access to the LAP, so that it knows which Interactive Tools are allocated to which Operator Modules. Thus, when the operator uses one of the Interactive Tools, for example by pressing a button on the touch-panel, the OM-Scheduler receives an interrupt from this device, and returns control to the Operator Module that has been allocated this Tool.

4.4 The "Knob" System

The use of the knobs. In parallel with the execution of various Operator Modules, the operator may want to "manually" adjust the values of certain control parameters. At each console there are four knobs for this purpose: they are handled by the Knob system.

This facility is independent of other software on the console and reacts quickly to any adjustments made, sending new values to the appropriate FEC, and receiving and displaying the corresponding acquisitions.

The system is sufficiently flexible to allow two types of control:

- (a) control of a parameter corresponding to a given equipment, such as a timing value or the current in a power-supply;
- (b) control of a "coupled" parameter, which represents a physical characteristic of the particle beam, such as the "harmonic correction" of 50 power-supply currents adjusting the beam trajectory.

In the second case, the coupled parameter can be defined dynamically from a keyboard: a useful facility for the machine physicist.

Operator interaction. The parameter to be controlled is chosen at the Main Touch-Panel, exactly as though it were an Operator Module: the operator descends the Main Tree until he gets to level 5, and presses the button corresponding to the required parameter. He then indicates which Knob he wants to use, by pressing the "SELECT" button on the Knobs panel (Fig. 9). The parameter is automatically "attached" to the chosen Knob.

Fig. 9. The knobs panel.

The Knob display shows both the initial and current setting of the Knob itself, and also the acquired value, read back from the equipment. As the operator turns the Knob, he sees the "control" value change accordingly. When the corresponding cycle type or destination arrives, the acquired value changes to match the control value.

The parameter continues to be attached to the Knob until another parameter is attached to the same Knob (the later request overriding the previous), or until the operator ascends the Main Tree beyond level 4: at level 3 (or "home") all knobs are cleared, since the corresponding parameters must be released.

The knobs software. This work is split between the console computers and the FECs; several software modules are used in each case (Fig. 10).

Fig. 10. The "KNOB" system

(a) In the console computer, the module "Read-Knobs" regularly scans the four Knobs, and sends to the FEC any values that are modified by the operator. This activity is asynchronous with the accelerator cycle, and the value is deposited in a "mailbox" variable on the FEC. Read-Knobs looks in another mailbox to see if there have been any errors, in which case these are displayed on one of the screens of the console.

(b) In each FEC, the "Knob-Processor" is synchronised with the accelerator cycle, and deals with requests from the Knobs on all consoles. For each active Knob, it calls the appropriate Equipment Module at a specific point in the cycle.

At a later time, it reads the parameter values (again by calling the Equipment Modules) and sends them to the consoles for display.

(c) Back in the console computer, the module "Write-Knobs" is (remotely) started by the Knob-Processor. The values given to it are displayed on the Knob display screen. In general, the value displayed is the latest acquired value of the attached parameter. In addition, the status of the equipment is also displayed, (e.g. for a power supply this could be "on", "off" or "standby"). There may also be a short message to indicate a control fault.

5. CONCLUSION

This system for selection and scheduling of Operator Modules, and allocation of Interactive Tools, has been in use since 1980, satisfying the differing requirements of the various types of "user" of the CPS Control System:

- the operator, whose job is to start up, adjust and survey the accelerators;
- the engineer or machine physicist, who designs new modes of operation;
- and, of course, the software engineers, who may want to test a new application program, or update a database, and without whom none of this would have been possible !

ACKNOWLEDGEMENTS

The success of this project owes much to many members of the "Controls" and "Operations" groups of CERN's PS Division. In particular, the Operations Group's wealth of experience of accelerator operation was invaluable during the specification phase.

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