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CONSOLES AND DISPLAYS FOR ACCELERATOR OPERATION

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Abstract

The first applications of computers in accelerator control were in areas where the human operator was not very effective, such as orbit correction, or the logging and comparing of many accelerator settings. A simple set of hardware buttons to select the programs, and a printer or storage scope to give the results, sufficed as operator communication. An important step forward came from the first completely computer controlled accelerator at Los Alamos. This introduced the concept of the operator's control console as a computer peripheral and sparked off an intense period of research into achieving a satisfactory "remote hand and eye" operation through the computer. A milestone in this process was the SPS console which added the touch panel idea from SLAC and the interpretive language from the Rutherford Lab. Many such consoles have become quite complex with a wide variety of input and display devices, and have been successful in supplanting the earlier control racks.

In recent years the complex control console has come under pressure from two directions. The first is from the success of computer control itself. Interaction from many places and at different levels has led to a demand for many more, but simpler, consoles. At the same time accelerator operation has moved to more algorithmic control or "modelling" which can manage with simpler facilities. Thus many recent installations are using simpler consoles, with the touch panel, colour display and shaft encoder predominating. The SPS console has its own dedicated mini-computer and fore-shadowed the networking concepts which are becoming so important in new control system designs. Accelerator consoles will now draw inspiration, even competition, from the new breed of local area network work-stations such as APOLLO, PERQ and SUN.

The paper traces the evolution of consoles and displays in accelerator operation, and how the way of using them has developed with experience. Possible directions for the future are discussed, with particular reference to the SPS/LEP developments.

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1. The operator's control desk

Before the introduction of computers, most accelerator control rooms had rows of racks with separate controls and indications for each piece of equipment. Some of the most important controls and indications were often grouped together with the telephones and intercom equipment on a central control desk, but the role of this control desk in the operation of the accelerator was very limited. Computers were initially used in applications where the human operator was not very effective, such as orbit correction, or the logging and comparing of many accelerator settings. A simple set of hardware buttons to select the programs, and a printer or storage scope to display the results, sufficed as operator communication.

An important step forward came from the first accelerator designed from the start for complete computer control. This was the 800 MeV proton linac at Los Alamos¹. The accelerator equipment was connected to the computer by a multiplex system and the operator had access, via the computer, from a control desk containing displays and other devices designed to interface the operator to the computer. This was the first of the "consoles" as we know them today, and sparked off a lot of interest in console design. The challenge was to replace the myriads of conventional hardwired controls and indications with "remote hand and eye" operation from a console, through the computer.

Important advances were the touch panel from the switchyard control at SLAC², the use of an interpretive language from beam line control at the Rutherford Laboratory³, and the tracker ball and cursor from the bubble chamber film scanning experience. Many of these ideas, together with experiments with displays, were tried as additions to existing accelerator control systems. A completely new accelerator, however, provides the best opportunity for a fully thought out synthesis, and this took place in the early 1970's for the SPS control system^{4,5}. Figure 1 shows an SPS console as used during the commissioning of the SPS. This was a milestone in console development and provided inspiration for subsequent machines such as VICKSI, PETRA, and JET.

2. The Mobile or Mini-Console

Mobile or mini-consoles have played an important part in the commissioning of the CERN Antiproton Accumulator (AA), JET, and the CERN Low Energy Antiproton Ring (LEAR). This is a more important development than it might seem at first sight. In the early days of computer control it was difficult to persuade equipment builders to economise and leave local controls and indications off their equipment. With the improvement in computer literacy and the microprocessor revolution, people now expect to interact with their equipment through some form of computer device. The problem is to maintain some form of coherence despite the large numbers and variety of the controls required. This coherence should be maintained between local and central controls, both from the point of view of the user and of the implementor/programmer.

One approach is to make the mini-console a subset of a full console, as shown in figure 2. Three of these mini-consoles were used for the commissioning and initial operation of the CERN AA. These consoles are quite similar to those used at PEP in that they consist simply of a touch screen and a display screen. This might suggest that a simple console is adequate when the underlying applications software is powerful and comprehensive. Another three of these mini-consoles, further reduced by using the touch screen also for the graphic display, are in use in the SPS control room for subsidiary duties. The main criticism of this approach is that the software is not compatible between the mini-console and a main console. A solution to this

Fig. 1 SPS Console during Initial Operation 1976-77.

problem is to make the mobile console an exact miniaturised version of a full console as shown in figure 3. This ensures complete software compatibility but is expensive and so is limited in its range of applications. Figure 4 shows the mobile console used in the commissioning of LEAR. It is perhaps intermediate between the two and nearest the optimum.

LEP will require many local and mini-consoles. Separate consoles for machine components and supporting services may be required at each access point "village". Also some of the machine subsystems, such as the RF plants, will require dedicated consoles for local maintenance and repair. Central operational control will be from the SPS control building, but as the office complexes are spread over several buildings in both the Swiss and French sites, additional consoles will be required.

The major challenge in the design for LEP is to achieve the triple objectives of low cost for the many mini-consoles, adequate power for central operational control, and compatibility between the central and local consoles. Subset compatibility would be a minimum requirement, but there are strong feelings that complete compatibility is required, so that any program can run on any console. The rest of this paper develops ideas on how this can be made possible.

3. The Personal Work Station

The recent development of personal work stations such as APOLLO, PERQ and SUN, is of great significance for the design of accelerator consoles. Up till recently most work on console design has been in specialised areas such as accelerator control, aircraft cockpits, nuclear power station control, computer aided design, where the numbers involved are quite small. The cost per unit has not been an important factor, but the total manpower devoted to their development has been limited. The personal work station, however, is finding mass applications

in office automation, education, research, and business. A large amount of effort, both from industry and research establishments, is being devoted to their development, and this will have a big impact on accelerator control.

The personal work station consists of three main elements: a high performance CPU; a display with high (1000 point) resolution and cursor capability; and a network connection. Figure 5 shows an APOLLO, one of four different makes of personal work stations currently installed at CERN for evaluation. More

Fig. 2 Touch Terminal in Control of Antiproton Accumulator.

important even than the hardware are the software concepts being developed for, or applied to, the personal workstations. Multi-processing, display windowing and network wide random file access, are the most relevant to accelerator consoles.

How this impact will be realised is not yet clear. Will consoles be built on the core of a personal workstation? Will some of their modules, hardware and/or software, be incorporated in a console built in a standard bus system? Or will they simply provide new directions and set new standards? Whichever way it goes, console design is poised for a big leap forward.

4. Networking

Early systems had the operator interface and the control of the accelerator equipment integrated into a single computer. This approach can be quite successful as it is easy to obtain a high bandwidth between the equipment and the operator. As the system becomes larger, however, this approach breaks down partly due to the complexity involved, partly due to lack of CPU power. Where the equipment to be controlled can be broken down into subsystems, or separate machines, the integrated approach can be given new life by having separate semi-autonomous computer systems loosely linked by a network for transmitting shared parameters.

Fig. 3 *Mobile Console in Control of PS Booster.*

A radically different technique is being developed in other fields of computing centred round the emerging technology of local area networks. Here each "node" or computer is function oriented, i.e. dedicated to, and optimised for, a particular job. Examples are a network with a file server, a print server, a gateway to other networks, and several personal work stations.

In accelerator terms this translates into separation of the equipment management functions and the console functions into separate machines connected by the network. This approach has been used successfully by the SPS control system since the beginning. For economy, however, the same type of computer and operating system were used for both the consoles and the process computers. For LEP a modular system based on a standard (VME) bus will be used⁶.

This will provide more flexibility in configuring the hardware and software for the varied tasks of the console computer assembly, the process computer assembly, and other assemblies required in the control system.

5. Multi-Tasking and Windows

The screen in figure 5 is divided into three "windows", two being used for graphics and one for text. The text window is temporarily "overlapping" the graphics windows so that all the text can be read. Each of these windows is the output of a separate process running in the work station. The user can interact with the process of his choice simply by moving the cursor into a window controlled by that process. The other processes can continue in the background, however, unless they are waiting for user input.

The touch terminal shown in figure 2 is at the other extreme, and interacts with only a single process in the AA control computer. This does not mean a single program, as programs can be run one after the other or in "tree" fashion. If several actions or displays are required concurrently this must be built into the single program, or another touch terminal must be used.

The SPS consoles have used a multi-processing system with some good results, but have been limited by two main problems. The first is how to handle the interaction. The solution was to divide the processes into one interactive process which alone could use the touch panel, ball and knob, and several (up to six) so-called "real-time" processes which could only access the accelerator and create displays. As the interactive process is the more powerful most jobs were programmed as interactive processes so if two were required at once, two consoles had to be used. The APOLLO feature of using "Pads" for the displays so that they can be overwritten and re-made visible at any time could be applied to the touch screen, knob, and ball, so that all

Fig. 4 Mobile Console in Control of CERN LEAR.

processes could be "interactive processes", with the interaction directed by the user rather than the programmer.

The other main problem with multi-processing in the SPS consoles is display allocation. The philosophy was to give each programmer the full console facilities, with the not surprising result that most processes use all the console facilities, particularly the two main displays, leaving nothing for any other process. Other systems, e.g. JET, pre-allocate the screen into different areas for different processes, but

this of course reduces the effective resources available to any single task. This problem is solved by the "window" technique. Each process can be given a display window, the equivalent of a whole screen, and can even "borrow" additional windows if necessary. Thus the programmer has no a priori restrictions. Whether these windows use the full physical screen(s), and whether they are overlapped or at the top of the pile, is not specified to the programmer, but determined by the user.

Another problem with multi-processing is the sharing and communication of data between processes. In the SPS this is mainly done using files on the library computer. With the increasing use of multi-processing in the consoles there has been a demand for more rapid and random access to common data. Experiments are under way to provide this for cooperating processes within one console. This could lead to two separate techniques for shared data, one for processes in the same console, another for processes in different consoles. The personal work-stations have attacked this problem by supporting "paging over the network". This is made possible by the high speeds of modern local area networks, and of course sophisticated software. This could form a mechanism for any process to have rapid random access to common accelerator data.

6. The modular control desk

Three consoles of the type shown in figure 1 were originally installed in the SPS control room, so that one could be used for primary operation, another for auxiliary control duties, and one say as a spare or for program development. After a few years' operational

Fig. 5 *APOLLO Personal Work Station
at CERN.*

experience a fourth console was added and the control room was re-arranged to give two operating areas, each with two consoles. One of these operating areas is shown in figure 6. This was done partly because the console limitations discussed previously often required the use of two consoles together, but also because many aspects of accelerator operation, particularly machine development and setting-up, are team efforts. Space and facilities for up to half a dozen people are often required at such times. Similar concepts of a large control desk with duplicated or repeated control facilities can be found elsewhere, for instance VICKSI⁷.

The control area shown in figure 6 provides a number of separately identifiable facilities. These are :

- 1) Analogue Signal display and processing
- 2) Alarm display and manipulation
- 3) Interactive accelerator control
- 4) Permanent (wall mounted) displays for "at a glance" status
- 5) Closed Circuit TV screens.

Figure 7 is a schematic diagram of a console module which, it will be argued, can provide all the above functions. The main display is, of course, a high resolution colour screen. Below this is the touch screen (probably also colour), and an auxiliary screen for programming and computer messages. As the technology improves this latter screen might be generalised into a full function auxiliary screen. Then there is a separate unit incorporating the keyboard, knob and ball, although the ergonomic placing of these might vary between a local control console and a central console.

The ability of such a console module to perform all the duties required for central control can be examined as follows :

Analogue signals. As accelerators have become larger the traditional technique of attaching a scope or spectrum analyser to the output connections of a sensor has become more and more difficult. This problem was tackled for the fast kicker signals on the SPS by using remote digitisers. This proved very satisfactory, and with increasing software support gave

Fig. 6 Control Area in Revised SPS Control Room.

additional advantages of automatic setting of gains, offsets, and associated timings, and at the display end the addition of scales, explanatory notes, calibrations, and zoom capability. Even for small machines such as the AA, transient digitisers in the economic CAMAC module form are finding extensive use. In the multiprocessing console of figure 7, one process (or more) might be devoted to reading an analog signal and displaying it on a window in some corner of the screen.

Alarms. The SPS alarm computer provides two functions. It accepts and manages alarm information from the accelerator; and it displays this information to the operator with the possibility of interaction at two separate points in the control room. For LEP two alarm computers may be used, one for services and one for machine components. It will be advantageous to separate out the operator interface part of the alarm system into a standard console module. A program in the console module will communicate over the network with the appropriate alarm computer. This will simplify the alarm computer software and will make alarm information available on any console, although in the control room some console modules will be dedicated to this function.

Interactive accelerator control. This is the main role of the console, and in the SPS the now NORD-100 based consoles have been steadily improved over the years to fill this role as well as possible. The new console would have all the same facilities as the old one, such as knob, ball, touch screen, program screen, and some special purpose buttons. There is a question over the number of main display screens, however. The existing console has three main display bays

Fig. 7 Proposed Console Module Layout.

containing four small monochrome screens, a low resolution colour graphics central screen, and a high resolution monochrome screen. Theoretically all of these screens could be represented as windows on a single high performance display, but physically this may not provide adequate display area for typical operations scenarios. The solution is to generalise the window capability from N windows on one screen to N windows on M screens. N would be some suitably high number such as 15, whereas M could be chosen according to the physical requirements. Even in a single bay local control console the auxiliary small program screen, and even the touch screen, could be extended to hold one or more of the logical windows.

Accelerator computations. In the SPS the large computations required for modelling, data reduction, and other calculation oriented control functions, are done in the console, usually as FORTRAN sub-routines called by the NODAL interpreter. The proposed console module must also have this capability, even though an array processor may be attached to the LEP network for the heaviest particle tracking computations. This should not be a problem as the console module will be based on a powerful 16/32 bit micro-processor. The MC68000 is the current CERN 16/32 bit standard and is also used in the APOLLO and SUN personal work stations. At CERN trials have shown that it is possible to take large programs from the central computers and run them with little modification on APOLLO. From the speed point of view, there should also be no problem. The current prototype of the console module uses a standard 8 MHz 68000 and can interpret NODAL faster than the NORD. Substantial improvements in the 68000 line of microprocessors are expected to increase the performance to levels approaching super-mini CPU's. Also the console will use multiple processors⁶, one processor per process. Local control consoles may support only a few processes for cost reasons, whereas the main central consoles could have more.

Closed circuit TV. Ideally we would like to transmit TV pictures over the standard console digital connection, then display them on any window on a screen. The bandwidth and processing power required for this are at the limits of current technology. Two areas of development are promising, however. The first is TV "CODEC" techniques of data compression already in use for video-conferencing. The second is the use of cameras with low resolution and low scan rate based on new semiconductor digital video sensors with resolution in the 300 x 200 region.

7. Conclusion

Given that all the functions described can be supported over the network by the single type of console module shown in figure 7, then complete compatibility between local and central control can be achieved as :

- a) The central control area can be made up of a number, say 6, of the modules.
- b) Local control with only one module can have complete access to all data, restricted only by the number of windows reasonable to use at one time.

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