IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

START-UP OF THE NEW CPS CONTROLS SYSTEM AND SWITCH-OVER OF THE 800 MeV BOOSTER CONTROLS

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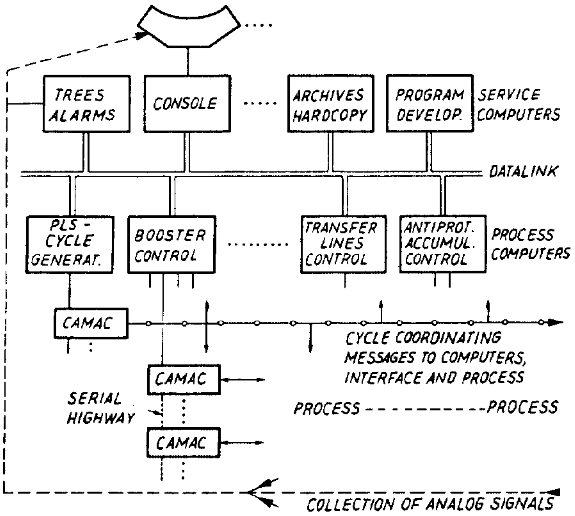
Abstract

The new CPS controls system[1] was successfully put into operation on 19 November, 1980, when the 800 MeV Booster, after switching over to the new system, was started up for particle physics. A subset of the new system had already been installed on the Antiproton Accumulator in Spring 1980 and has reliably served several months of engineering run. The Booster machine and control of the CPS cycle generation are now routinely operated by the new system which is based on distributed processing, extensively applying microprocessors in the interface. The problems encountered in converting existing accelerator controls, the control switch-over itself and operational experience gained up to the date of the conference are described.

Introduction

The objective of the CPS controls project is to provide an integrated and homogeneous controls system that will allow operation of the CPS accelerator complex from one central control room. Involved are Linac(s), PS Booster, 28 GeV Synchrotron, Accumulator for antiprotons now, later for electrons and positrons, transfer lines between these and to destinations like SPS, ISR, 25 GeV physics and LEAR. Service aspects and maintainability are strongly emphasized.



The diagram is self-explanatory. Details are in the references. Features highlighted are:

I. The CPS controls project is one in which the required operational[2] and accelerator engineer's aspects were systematically synthesized and included in the specifications with a high weight.

II. The CPS accelerator complex and its controls, are unique in that interleaved cycles[3] of different particles and beam properties are produced and transferred to different destinations. Sequence and properties of these cycles are created on the control consoles and are controlled by a computer-based system, the Program Line Sequencer (PLS), which sends out coordinating messages to controls system and process hardware.

III. The new CPS controls system makes extensive use of distributed intelligence.[4] There is a microprocessor-based Auxiliary Crate Controller (ACC) in most CAMAC process interface crates. The ACC's tasks are (i) cycle parameter refreshment, (ii) buffering fast data bursts from beam instrumentation and (iii) some preprocessing; by-products are unloading of process computers and local autonomy, giving graceful degradation.

IV. The system makes use of a modular, telephone exchange-like analog multiplexer network[5] for central console display of key analog signals from the whole accelerator complex. The bandwidth is up to 25 MHz, channels are computer selected from touch pannels.

V. Crucial for the service and maintenance aspect and indispensable for the conversion, is the local access to the controls resources at different levels.[6] This provides the means for multiple parallel checking, essential for switch-over and maintenance during accelerator stops. It also allows flexible and selective online diagnostics and patching.

The table illustrates the size of the system.

	now	later
. process variables (many modulated at 1 Hz (PPM))	$4 \cdot 10^3$	10^4
. application program modules	$5 \cdot 10^2$	10^3
. console software, expressed in lines	$4 \cdot 10^5$	$4 \cdot 10^5$
. systems software, expressed in lines	$5 \cdot 10^5$	$5 \cdot 10^5$
. general purpose consoles (central)	3	5
. autonomous microcomp. + terminals	10	15
. 16 bit minicomputers	14	20
. 16 bit microprocessors	35	100
. CAMAC (or CAMAC related) crates	100	200
. CAMAC (or CAMAC related) modules	2000	4000
. 8 bit microcontrollers	1300	2600
. multiplexers for analog signals	300	600

Conversion, Switch-over, Start-up

Conversion of existing accelerator controls meets two major obstacles: (i) every piece of equipment is affected and every individual is more or less involved. This implies historical "faits accomplis" and discussion partners with good controls competence but of heterogeneous opinions. (ii) the constantly running accelerators leave no time for tests with process hardware except in long annual stops; then too much must be done in too short a time which must be shared with urgent maintenance activities.

Point (i) implies that human communication is a substantial part of the job (a) for reaching workable compromises between cost and homogeneity, and (b) for defining what the system should do and look like for operation. Aspect (a) was dealt with by a cumbersome but ultimately successful exercise which yielded accepted process interfacing standards, a complete set of interfacing modules and performance specifications for each module. After prototyping the non-off-the-shelf material in 1978 and tendering, production and delivery started in 1979. In a second round of discussions late 1979, with specialists of the Booster, timing, operations and software, a detailed layout of the Booster and PLS interfaces was agreed upon. It implied non-negligible restructuring of existing equipment, either for homogeneity or for new requirements. Aspect (b) was dealt with by including a permanent operational aspects section in the project group: their task was to draw up comprehensive and consistent specifications for future operation. This yielded agreement on the means of interaction (consoles) and relevant input for definition of the software. The result is a highly modular software layout. In addition to the modules specific to one application each, there is the systems and console software, and the so-called applications skeleton which coordinate and arbitrate their execution. The

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skeleton was designed and standard protocols were defined in 1978 so that production started in 1979.

This is where point (ii) comes in. After pure software tests and tests with the interface, further progress can only be made with process equipment and, for beam instrumentation, with the beam itself. Between Spring 1979 and Summer 1980 (the long stop meant for switch-over), there were only 2-day stops every five weeks, three 2-week stops and 100 hours machine development time (with beam) available for the project. Careful preparation allowed efficient use of these short periods of availability. Late in 1979 the complete applications skeleton and a representative sample of specific modules were successfully tested from the first console down to the process. This was a crucial milestone confirming the viability of the concepts used and giving the confidence that it was now "only" a matter of time and hard work. A second encouragement came when in Summer 1980 the Antiproton Accumulator started up, reliably served by the standard interface and lower level software modules,[7] supplied as a fringe activity to the Booster conversion.

Of the four months (mid-July to mid-November 1980) switch-over shutdown, the first 1½ months were taken for hardware switch-over and checkout, the second 1½ months for overall system tests including software. The last month was used for beam tests. Since time was short, applications people (the last in the chain, with a fixed end date) worked incredible hours. The beam tests proved to be the most effective period, since all relevant people were available simultaneously and the beam reveals bugs otherwise tedious to find. The month of beam tests was exceedingly hectic. For outsiders the situation was disconcerting; few people had the overview, and their confidence level at that time remains a secret. As by a miracle the situation fell into shape the weekend preceding the scheduled start-up date and - after some hesitation - it was decided to go ahead. The start-up was successful and thanks to a strong presence of all participants the run until Christmas attained about 92% of its planned operation time with only 1.6% downtime attributed to the new controls system.

System Software[8]

The topology and the tight timing requirements imposed a weighted coexistence of interpreted software (consoles) and compiled code (process computers), so the systems software had to provide a stable environment for both interpreted and compiled applications programs. Thus for the operating system, the network package, languages, libraries and methodologies a compromise had to be sought between performance and protection, and maintainability had to be maximised.

The network (adapated from SPS) was running using the computer manufacturer's operating system, and the Nodal interpreter (also adapted from SPS) was available some two years before beam date. Libraries and facilities for compiled programs were added progressively, and real-time Pascal one year before beam date. Thus, a stable basis was provided for applications development. For the three months encompassing the start-up of the new PSB controls, systems software modifications were restricted to corrections considered essential; there were nine such corrections. Help for users of the system software, i.e. the applications programmers, became a full-time job during this start-up period.

Performance and response-time constraints (delivery of several hundred data points to display screens every 650 ms cycle via the network) dictated the use of relatively unprotected mechanisms to access serial CAMAC, the data links and certain files. Relevant drivers reside in a global common area and applications using the links or CAMAC run on a high privilege-level. In all other cases, conventional operating system protection mechanisms are used as much as possible.

Experience during the start-up period confirmed that the system performance is approximately as expected, provided that enough physical memory is available to eliminate disc thrashing. File access time is in certain cases excessive, so a rapid-access file package which has been implemented will be put into service shortly. Still, an occasional unexplained systems crash must be interpreted as the price of sacrifice of protection for speed.

Consoles[8]

During start-up, two groups of users must share the various resources: (i) the builders of the different software and hardware elements, (ii) the machine operators who must prepare the machine.

Three access levels[6] to the controls system are vided: (i) autonomous access to the process hardware using mobile microcomputers and terminals, (ii) access to the process through mobile terminals connected to the process computer, (iii) access through main operator consoles in the control room. These last two are directly involved in the start-up.

The mobile terminals (ii) available since the setting-up of the CAMAC loops, proved extremely useful for (a) verifying that all hardware is running properly, (b) verifying, by direct access to the process variables, that programs execute correctly, (c) interactive access for debugging the microcomputer programs in CAMAC. The mobile terminals have proved indispensable at run-in. During routine operations of the accelerators, they are locked out.

Three main operator consoles were in use during start-up; two were available for operations, the third was reserved for software testing and debugging. The great care put into the inherent security of the interactive software tools proved to have been absolutely essential and effective. For any conceivable interactive manipulation, deadlock situations are avoided. Moreover, the provision of features to unblock application programs has turned out to be very useful.

The use, in the control room, of a terminal connected to the console computer, enabled us to check the proper functioning of a complete control activity and to make patches. Not initially foreseen, it allowed quick deblocking of many an awkward situation.

Process Interface[9]

The process interface was structured to keep coupling between subsystems weak to provide sufficient autonomy. This proved very helpful during the stepwise installation and tests of subsystems. One aim, graceful degradation, was convincingly demonstrated when proton production continued - even beam property modulation - while the process computer was down.

Relieving the process interface of real-time constraints by distributed processing and separation of data highways from channels transmitting time-critical events, proved effective when, during tests, the cycle time was reduced to 0.3 s and no sign of saturation of the process interface was found.

Providing generous numbers of analog signals on the consoles proved crucial also as fall-back in case of other impediments. Due to the large bandwidth of the system and geographical distribution over the whole site, maintaining a high signal to noise ratio in all branches was no mean task.

Much emphasis was put on diagnostic tools, hardware and software, on-line and off-line. They became available in the prototyping stage of the standard modules, giving benefits in all phases: prototype testing, production in industry, acceptance at CERN, installation and on-line debugging. Diagnostic procedures were a crucial element in the comprehension between designer and producer. Diagnostics are possible from all access points to the system. It became an early habit to start diagnostics of the process interface right from the main consoles. Now operators can coarsely locate failure sources or even cure some before the expert gets in.

Thorough quality control of incoming hardware and a one-week temperature cycling followed by an exhaustive test eliminated most failures otherwise occuring within the first months of operation. This intense care proved justified in the wide application of microcomputers where hardware and software failures superimpose. Early crashes due to hidden software faults occurred, but after debugging the reliability has increased to a level exceeding that of the process computers.

Applications Software[8,10]

The applications program production effort for the Booster and the cycle program generator was estimated at 40 man-years, while little more than 1.5 years were available. Accelerators were continuously in operation and the 4 months installation shutdown had to be shared with other activities. This left effectively 2.5 months for application software tests during this shutdown including 1 month beam test. The planned start-up date was met, but only at the cost of an extreme effort of the applications people involved working long overtime for months on end.

Though testing was correctly estimated at 20% of the total production effort, i.e. with the interface and equipment, first without beam (10% = 4 man-years), next with beam (10%), the elapsed time was too short. Even though the software skeleton and its major control functions, including beam property modulation, had been tested with the corresponding hardware earlier in the year, the bottleneck was clearly the tests with beam. Only the actual beam tests could bring all people together at a sufficient alert-level for efficient systems debugging in an environment where tracing of bugs has to occur within hundreds of modules, software and hardware, and their myriads of interrelations.

Those tests could only be performed by a reduced team of applications people who had an adequate overview not only of the software structures but also of the interface hardware and process equipment. They collaborated with accelerator engineers who had a key part in defining the operational aspects and were thus familiar with the new controls environment and knew what every program was supposed to do.

While - throughout the project - process hardware and interface hardware were only available for tests in a very restricted way, the process computers were available most of the time until beam date. Then all these machines went on-line and access to them for new installations became very limited. For the next instalment of the project the need for a dedicated test computer, which would provide comprehensive environment in which most software could be tested, became apparent. Similarly, there is now competition for consoles between operations and software testing, but with 5 consoles this should be bearable.

Operational experience

Three months after start-up it is too early for balanced appraisal of a complex new control system: first, because of inevitable bugs and teething problems; second since some attractive facilities are still due; third since the users have not fully made the conceptual switch from old to new controls.

The feasibility of the following guiding concepts was proved: (i) control from one central room, (ii) general purpose (non-dedicated) consoles, (iii) trees structure for accessing relevant accelerator parts, (iv) parameter reservation in multi-operator environment, (v) different access according to operational mode, (vi) comprehensive alarms, (vii) working parameter sets reflecting virtual machines, (viii) direct analog signals at one's fingertips.

Operation was impeded by four groups of problems.
(i) Numerous bugs gave wrong synchronizations, wrong cycle generations, microprocessor hangups, interaction blockages and ambiguous alarms. These have been a very trying, indeed disconcerting experience for operators and accelerator engineers, but it was mostly taken with comprehension, realizing the constraints under which the system had been brought into being. Fortunately, the frequency of intervention required from controls specialists diminished quickly during the first few weeks of operation and the problems affected proton production rather little, since process equipment kept working on local data registers.
(ii) The system having become available in the nick of time, no hands-on operator training was possible. Only two machine engineers , involved in the start-up were really well informed, having participated in the project. The difficulty of the mental switch to new structures and underlying logic, new interactions and displays for an intricate accelerator complex, creates an enormous load. More so when the $\bar{p}$ venture superimposed substantially more complexity at the same time.
(iii) The speed of interaction (calling and making applications work) of the present tree software is slower than the old controls. This is due to multiplicity of actions possible, the virtual machine concept and technological constraints like the file system and the speed of the NODAL interpreter. An improved, compiled version of the trees software, using the rapid access file system is planned.
(iv) No new system can be superior to an old one in every detail, some will be less and some (hopefully more) will be better. Progress must thus come from an overall gain. Presently, some of the attractive facilities (global commands, etc.) are still being finished.

The mentioned mental switch is even more difficult when specifying what one wants of a new system still to be built. This led to some reappraisals of original specs. Rearranging some sets of process variables in the trees has improved manipulation speed. The general purpose consoles, where any display must be called, create the wish for more permanently available key displays. More of these mild reappraisals are likely.

All in all, a good deal remains to be completed and improved. However, all accelerators are working, the initial strong tension in the new control room has visually given way to a more relaxed atmosphere today, and the recent $\bar{p}$ successes at PS speak for themselves.

Acknowledgement

Our gratitude goes to all those PS staff and visitors, without whose constant cooperation this job would not have been done.

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