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DEVELOPMENT OF AN ON-LINE CONTROL SYSTEM FOR THE RF
SEPARATED HADRON BEAMS TO BEBC

I. Lehraus and W. Tejessy

CERN, Geneva, Switzerland

ABSTRACT

An on-line control system to tune and monitor separated particle beams to the Big European Bubble Chamber is described. The system includes controls of magnetic elements, collimators, rf-separators, multiwire proportional chambers and scintillation counters. Based on a PDP-8/e computer, the development of this system from a small satellite computer linked to a PDP-15 to a disc-based operating system is described. The hardware layout of the controls and the structure of the employed software are discussed.

1. INTRODUCTION

In an earlier paper [1] we discussed in detail the layout and functioning of the monitoring and control system for the high-energy beam lines leading to the 2 m hydrogen bubble chamber in the CERN East Area. This report describes a corresponding system which has been developed for the rf-separated hadron beams feeding the Big European Bubble Chamber (BEBC) in the CERN West Area. The presented system worked satisfactorily for the hadron beam, U7, from the 28 GeV/c Proton Synchrotron (PS) and it will be used without any major modifications for the high-energy hadron beam, S3, from the 400 GeV/c accelerator.

The layout of beam line and components are similar to the East Experimental Area set-up and will therefore be discussed only superficially. We shall concentrate mainly on those aspects of the control system which have been developed differently, especially in connection with organization and structure of the computerization.

The U7 beam to BEBC originates at an external target 204 m from the centre of the chamber. It is a radio-frequency separated beam with two or three active cavity separation. The magnetic elements are six standard PS bending magnets and seventeen quadrupoles as well as a superconducting quadrupole and a superconducting bending magnet. The nine variable slit digitally controlled collimators and ten multiwire proportional chambers for beam profile measurements were developed by the CERN Track Chamber Division Beam Group and are, in design, similar to the East Area beam components, as is the beam stopper. The beam consists of three stages: momentum definition, mass separation and a final cleaning stage which together require up to 6 focal points in the vertical and 7 in the horizontal plane. This complexity is the cause of the rather lengthy tuning procedure needed and the reason for the special interest in providing a central control system designed to minimize the tuning time and assure efficient continuous monitoring of the beam parameters.

2. GENERAL STRUCTURE OF THE CONTROL SYSTEM

Our prior experience has shown that the use of a computer in a beam control system greatly increases the effectivity of tuning and monitoring

due to the wide use of automatic profile scans, plotting and logging. It was therefore decided from the start of planning in 1970 to tailor the control system to use with a computer. At that time a PDP-15 computer with 32K words of core memory, fixed-head disc and DEC-tapes was under discussion for the BEBC control. This computer was finally installed in the BEBC control room, adjoining the beam control room. For reasons of economy it was decided to link the beam control system to this machine. Nevertheless it was quickly realised that the addition of a cheap mini-computer in the beam control room as a multiplexer and remote interface to the PDP-15 would reduce construction cost of the control system and increase reliability due to better interfacing possibilities and to less interference with the PDP-15 programs. For reasons of compatibility and price the choice was made of a PDP-8/e with 8K words of 12-bit core memory and an ASR 33 teletypewriter as only peripheral.

With this decision the concept of a centralised control and multiplexer as used in the East Area could be dropped in favour of the simpler approach of separate controls for each group of functions, e.g. currents, separators, etc., with the daisy-chained external input/output bus of the PDP-8/e providing the multiplexing.

Figs 1a and 1b show the front panel arrangement with indications and manual access to the various controls, of which each is a separately addressable external device to the PDP-8/e, with push buttons allowing switching between MANUAL and COMPUTER control mode. The corresponding block diagram for the complete on-line system is shown in fig. 2. The control for "MOVEMENTS" allows for manipulation of the 9 collimators and a beam stopper. The positions of these elements are read and indicated from non-ambiguous-code encoders with 0.1 mm precision. For the computerization, the "AUTOSCAN" panel plays a special role in that this set of thumb-wheel switches and function buttons forms a very convenient mode of entering requests and boundary values into the computer. The interface for point-by-point plotting on the 611 storage display scope is incorporated. A real-time "CLOCK" forms a separate device together with "ROLL" and "FRAME" number from the BEBC data box as well as scalers

for target monitor and total flux scintillator counter. This information is fed into the computer between synchrotron cycles. The "RF-SEPARATORS" control allows for steering of relative phase, power and time dephasing of the three rf-cavities as well as frequency readings via a serial data link to the local controls in the beam line. The "DIGITAL INPUT/OUTPUT" interface is a general facility for input/output of 12-bit computer words. "SCALERS" for accumulating PS bursts, target monitor and total flux are interfaced separately for various bending-magnet and collimator scans.

Normally the controls have a direct access via parallel buses to the beam elements to be manipulated, an exception being the "CURRENTS". Here all requests are conveyed to a Siemens 301 computer situated in the West generators building, which has control over the power supplies for the beam elements [2]. The communication is realized via single 24-bit word transfers over a 900 m long parallel data link. There is one exception, the superconducting magnet, which is controlled directly.

The internal hardware structure of the individual controls and their interfacing could be illustrated using the "WIRE CHAMBERS" as an example. There are 10 multiwire proportional chambers in the beam line, with 64 wires per chamber and an effective spatial resolution of 1 mm. The chambers work in an integrating analogue mode feeding 64 central ADC's with 8-bit resolution. The profiles are accumulated in 64 four-decade BCD scalars. The chambers at the rf-cavities, and certain other chambers as well, can be remotely turned for either vertical or horizontal profiles and, if needed, descended out of the beam in order to reduce multiple scattering.

Fig..3 shows the organization of the interface, in this case for the wire chamber control. Three device numbers are allocated to this control (3 device selector modules are used, giving the possibility to use up to 9 different IOT strobe instructions). The corresponding input/output word patterns to operate the device are shown in fig. 4. With the manual/computer button, access to all preselections and actions can be given either to the panel switches or to the computer program.

Fig. 5 shows in more detail the essential parts of the readout for the 64 four-decade scalars. The selected scalar content is transferred via a

multiplex system into a shift register, advancing the bit selection scaler. Using a 4 MHz clock this operation takes about 4 μ s. This readout cycle is started after each PS cycle and when the scaler address is changed (manually or by the computer). A multiplexed overflow chain gives a flag signal and stops the counting.

Fig. 6 shows the generation of skip flag and priority interrupt, as well as flags related to the action - end of action cycle. Any action e.g. MOVE IN, is executed and when finished (i.e. "IN" is indicated) a signal, END OF ACTION (EOA), resets the ACTIONS buffer register. In case of computer control the skip flag and, when enabled, the priority interrupt are set and sensed by the program. The COUNT - COUNT STOPPED - END OF COUNT (EOC) - SKIP sequence works in a similar way.

3. DATALINK PDP-8/e - PDP-15

It is clear that for a mini-computer with no peripherals the data-link to the back-up computer forms an integral part of the computer system. Since the PDP-15 is used primarily for the monitoring and control of BEBC and the PDP-8/e remains the only satellite computer, the main design goal was to reduce as much as possible the interference with the PDP-15 Monitor System to allow the latter to evolve freely without constraints due to the link.

The existence of a powerful PDP-8/e cross assembler FRODO [3] on the CERN CDC 6600 (together with the non-availability of a similar assembler under the real-time monitor system of the PDP-15) made it a logical choice under the above circumstances to transfer all program development to the CDC 6600 and produce absolute binary loads for the PDP-8/e onto paper tape on that computer for transfer to the PDP-15. This reduced the main task of the PDP-15 to storage of the various core loads on disc and transfer on request of each load through the datalink to the PDP-8/e. To this may be added the transfer of data to the PDP-15 and its DEC-tape unit for special tests, as will be described later.

Since the datalink need not be very fast, the simplest solution was to use programmed transfers to avoid the complications of direct memory access. The cable length between the computers is only about 30 m, so that parallel data transfer is still economical. Fig. 7 shows the details of the hardware. Separate 12-bit wide balanced twisted pair data paths are used in each direction. The transfers are steered by a SEND and a RECEIVED flip-flop for each direction. The transfer cycle is very simple: an I/O pulse from computer A strobes the information from its I/O bus into the output registers, sets its own SEND flip-flop and computer B's RECEIVED flip-flop. If B has its (automatic) program interrupt flip-flop in the interface enabled, an interrupt occurs and the "SKIP ON FLIP-FLOP SET" instruction senses the origin of the interrupt. Computer B strobes the data into its accumulator and resets its RECEIVED and A's SEND flip-flop. This will be detected at A by a program interrupt if enabled and a new cycle can start. Often it will be preferable to idle on the corresponding SKIP ON FLIP-FLOP SET instruction with the program interrupt off, to avoid switching overhead, but this is a question of software techniques. Due to the use of two data paths concurrent transfers in both directions are possible.

In order to facilitate debugging procedures, indications of status for all data lines and flip-flops are incorporated, as well as a switch for manually disabling the interrupt possibility.

4. REALISATION OF THE HARDWARE

The beam control elements, interfaces and datalink hardware were realised using the DEC M-series module system standard and home-made special cards. Without interconnections to panels and I/O cable cards there are some 500 cards, including 64 scalars for the wire chambers. The system was split into two 19 inch wide 12 row high blocks housed in two adjacent racks. The beam side of the datalink (28 cards) was separated from the bulk of the control circuits.

The mini-wire wrapping on the H803 connector blocks was done semi-automatically using computer-generated wiring lists [4].

5. LINK-ORIENTED SOFTWARE

The PDP-15 runs under the RSX monitor. This is a multi-tasking real-time monitor using fixed partitions for the various tasks. Such a monitor lends itself very well to use of a programmed transfer link, since it allows lengthy idling on a very low priority in one partition on a "SKIP ON FLIP-FLOP SET" instruction without blocking the other tasks or noticeably altering response time. This allows block transfers without resorting to an interrupt after each word, which would cause high overhead.

With the set of programs used, an initialisation routine allocates a contiguous space on the PDP-15 disc, on to which the (variable sized) core loads from the CDC 6600 are sequentially placed and designated by numbers. To start the link an interface handler attaches itself to the link interrupt slot, enables its automatic program interrupt (API) flip-flop and waits for receipt of a code word from the PDP-8/e while relinquishing control of the central processor. Depending on the code arriving with the interrupt, either the "TRANSMIT" or "COLLECT" task are called into a different partition. The transmit task gets the requested core load from the disc and sends it to the PDP-8/e in a program loop, which interrogates the "SEND" flip-flop (and the "RECEIVED" for error messages back from the PDP-8/e) after every sent word continuously until acknowledgement by the PDP-8/e. The "COLLECT" task works on the same basis but for incoming data blocks, which can then be stored on disc and DEC-tape. The latter was used for test measurements for the External Particle Identifier [5], for which approximately 25 DEC-tapes of data were collected via this link for analysis. It is not used during normal beam operation.

The PDP-8/e bootstrap consists of an autoloader program read in from the teletype reader, which calls in the resident core loads via the link. This resident part includes routines to call in and start the various overlay core loads from the disc as they are needed during the run.

5.1 Performance

With this link set-up the framework was given for a reasonable set of working-routine overlays from disc for the monitoring and control of the

beam line. We will not elaborate on these at this point, since they are functionally identical to equivalent routines on the extended PDP-8/e to be described below. The system came into operation with the start of beam tuning at the end of 1972 and showed good response time and absolute reliability for the link, giving the user the advantage of a mass storage based overlay scheme. Its main shortcoming was, partly foreseen, the time needed for correcting and developing programs on a separate computer.

5.2 Extension of the PDP-8/e

The design of the system as described until now was based on the unavailability of any reasonably priced mass storage for the PDP-8/e. With the announcement of a new 1.6 million word moving head disc and a programmed-transfer DEC-tape unit together with a new operating system, OS/8, for this computer, a reappraisal of the design became interesting and this for various reasons.

On the one hand, disc space on the PDP-15's fixed head disc was becoming scarce and the cost of storage would be less on a moving head disc, especially in the long run, when the added complexity of beam control for the beams from the 400 GeV/c accelerator was taken into account. On the other hand, program development work on the CDC computers had shown more shortcomings than expected. The assembler FRODO was written for the CDC 6600 under the CERNSCOPE operating system. With the changeover to the larger CDC 7600 under CDC-SCOPE and the foreseen removal of the paper tape punch from the former, much work would have been necessary to produce a valid assembler for the 7600. But the more critical problem lay in the fact that paper tape output was practically no longer used on the CDC machines at CERN and when it did get used caused problems of an organizational nature, which greatly increased job turn-around time, e.g. tapes not punched, damaged, lost, etc., and made program development very inefficient.

It was therefore decided to revert to program development on the PDP-8/e under OS/8 and to enlarge the computer by a moving-head disc unit for the OS/8 system and the real-time programs as well as a programmed-transfer DEC-tape unit for files back-up and paper tape equipment for system start-up

and maintenance. These extensions were delivered in April 1974.

5.3 Software for the Extended System

The chosen monitor, OS/8, is a disc based system which includes all facilities to develop programs on the machine, such as File System, Editor, Assembler, Fortran II Compiler and Loaders to run the user programs. It has no real-time facilities and runs with the Program Interrupt disabled, so that a special real-time mode had to be developed. A feature of special interest in our case is the chaining possibility of user programs via a monitor request from the running user program, which calls the requested program from disc as a named file and enters it. The chain links are swapped with the monitor so that the links can use all of available core (with the exception of bootstraps in the top 128 word page of each 4K memory field). Since the pages to be included in a chain link are specified at chain building time, this allows a flexible sub-overlay structure with the non-overlaid pages remaining unaltered.

This again leads to the possibility of a main chain link, which normally remains in core (except during monitor swaps) and a set of overlays which form the various user tasks. Once the main link has control of the machine, it runs as a stand-alone program without any restrictions as long as it avoids monitor calls, and can therefore enable the program interrupt. The main link (written in Assembly Language) contains the necessary routines to service the interrupt via skip chain identification as well as the drivers for the teletype, keyboard and storage scope, which, together with the Autoscan panel, are used as real-time interactive peripherals. Tasks are requested from the keyboard, other tasks or external-interrupt routines through entry in a ground level queue in the main link and executed on a first-in, first-out basis. There is no priority scheme. Table I gives an idea of the core lay-out with the main link loaded. When an overlay task is loaded, the main link is in fact partially swapped out and the overlay first added onto the disc swap area, but this remains transparent to the user, since it is swapped back in before control goes to the specified start address in the overlay. So the overlay can correspond freely with

the routines of the main link and, for instance connect to the skip chain, use common data, subroutines, etc. On exit a task can either directly call a sub-overlay or return control via the ground level queue to the keyboard listener, which awaits the next request via the teletype.

Chaining to (non-real-time) Fortran routines is an added feature, which enlarges the flexibility of programming. Fortran routines are difficult to fit into the overlay area, but since COMMON area is preserved by Fortran links, it is possible to overlay even the main link with a Fortran program, saving only the restart parameters and the data to be passed on in COMMON, and to recall the latter from the Fortran routine when its input/output has finished. Obviously this overlaying is restricted to situations where no other tasks are pending and a veto is set accordingly.

A further attraction lies in the speed of switching via a monitor call from the user to the OS/8 monitor to allow running of completely separate programs including program development. The switch back to the main chain link is with a one-line command.

5.4 Implementation of User Programs

To give an idea of the possibilities of the described set-up, a short summary of the main sequences that have been implemented follows. Operator interaction is via the teletype or, mainly for scans, the Autoscan Panel:

- Plot of any wire chamber profile on the scope by simple pressing of a PLOT button, scaled by a preselected scale factor.
- Printout of wire-chamber profiles on the teletype.
- Integration over all wires of a wire chamber.
- Logging of currents, positions of collimators and beam stopper, rf-separator parameters. Error conditions are signalled.
- Automatic scan of any collimator across the beam, either as a slit scan or as a one-jaw scan between predefined limits. At each step the flux through a paddle counter BC1 in front of the chamber is summed for a preselected number of bursts and the result displayed on the scope, rescaled if necessary. At the end a teletype printout is given.

- Automatic scan of the current of any magnet, or magnet-doublet, in the same way as for collimators.
- Automatic scan of the phase between two rf-cavities to find the narrowest image on the wire chamber in front of the beam stopper. At each step, after counting n bursts is finished, a Fortran overlay is called to calculate the mean and variance of the profile curve and print them out.
- Calculation of the mean and variance of any wire chamber profile.
- Long-time accumulation of the counts on the paddle counter BCl in front of the bubble chamber to form an intensity distribution of the particles entering the chamber (FLUX routine). Special commands, apart from steering the accumulation periods, allow a display on the scope during accumulation as well as a final printout.

One of the design goals was to make the output from the programs similar to the older system described in [1] in order to facilitate their use by external groups; therefore we refrain from giving printout examples to avoid repetition.

6. CONCLUSIONS

To conclude, it may be said that the described set-up using the OS/8 monitor has been running reliably since September 1974 and the PDP-8/e system has shown its worth in reducing tuning time and errors. It has also proved to be very flexible and remarkably powerful for a 12-bit word-length machine with only 8K words of memory. In performance it, in fact, surpasses the East Experimental Area beam control installation, which uses the larger 18-bit wordlength PDP-9 with 16K words of memory and 3 DEC-tapes running under the Advanced Monitor.

As stated, the system here described will be used with few alterations for the new high-energy hadron beam from the 400 GeV/c accelerator. For the future a connection to the Nord-10 computers in the West Area Beam Control Room [6] is under study to allow further developments towards more automated tuning and monitoring sequences.

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REFERENCES

- [1] P. Lazeyras, I. Lehraus, R. Matthewson and W. Tejessey, CERN Yellow Report (CERN 74-1) and Nucl. Instr. & Methods 123 (1975) 11.
- [2] B. Danner, H. Ullrich, CERN/MPS/PO/71-2.
- [3] FRODO Cross-Assembler by G. Brandon, private communication.
- [4] J. Joosten, CERN/DD/DH/69/22.
- [5] M. Aderholz, P. Lazeyras, I. Lehraus, R. Matthewson and W. Tejessey, CERN/D.Ph.II/BEAM 74-1 and Nucl. Instr. & Methods 118 (1974) 419.
CERN/D.Ph.II/BEAM 74-5 and Nucl. Instr. & Methods 123 (1975) 237.
- [6] A. Ball, G. Cavallari, D. Jacobs, G. Sigurdsson and W. Tejessey, CERN/D.Ph.II/BEAM 75-2.

TABLE I

Page	Field 0 (4K words)	Field 1 (4K words)
0	constants and pointers	constants and pointers
1	ground level queue	common area
2	overlay handler	
3	program interrupt service	
4	teletype driver	arithmetic package
5	scope routines	
6		
7		
8	resident task (FLUX)	spare
9		
10		
11	TASK OVERLAY	
12		
13		
14	AREA II	TASK OVERLAY
15		
16		
17	AREA I	
18		
19		
20	output formatter	
21		
22		
23	scratch area	
24		
25		
26	OS/8 monitor bootstrap	OS/8 monitor bootstrap
27		
28		

FIGURE CAPTIONS

Fig. 1 Layout of manual controls and indications in the beam control room.

Fig. 2 Block diagram of the on-line system.

Fig. 3 Wire chamber interface.

Fig. 4 Input/output word pattern.

Fig. 5 64 wire chamber scalers' read-out structure.

Fig. 6 Priority interrupt, skip and end of action flag generation.

Fig. 7 Datalink hardware.

Fig. 1(a)

Fig. 1(b)

Fig. 2

WIRE

CHAMBERS

COMPUTER OUTPUT

COMPUTER INPUT

Fig. 4

Fig. 6

PDP - 15 SIDE

Fig. 7