COMPUTER CONTROLS: STATE OF THE ART AND FUTURE DEVELOPMENTS

J. T. Hyman

Rutherford High Energy Laboratory, Chilton, Berks., England

Abstract

A review of the current state of the accelerator computer control art is presented and a number of interesting new developments highlighted. An attempt is made to indicate future lines of development in the next few years.

1. Introduction

Presenting a paper on "....., the state of the art" seems to me to be an ideal way to "lose friends and repel people". Someone is almost bound to feel their achievements have been played down or even overlooked completely.

I intend to obviate the problem by claiming a measure of diplomatic priviledge for an invited paper to a general audience and to say that this is my personal assessment of the field. A tremendous amount of work is going on all over the world and it is quite a task keeping up to date.

2. Uses of Computers

When the idea of using a computer in an accelerator control system was first mooted - in the early 60's, I think people had closed-loop applications specifically in mind. Since then, many other facets of the use of computers have been explored. In an attempt to present a coherent picture, I feel it's worthwhile to run down a list of laboratories and to pick out a few interesting features of their work. In most cases groups have restricted their studies to a few topics, probably because of limited resources of money and manpower.

2.1 Argonne

There are two systems of interest, namely the large CDC 924A in the ZGS control room and the XDS Sigma 2 on the 7^{o} beam line.

2.1.1 ZGS

This system provides something of a control room "number crunching" facility, in addition to its main functions in the control system. These are the analysis of accelerator data and presentation to the operator, on demand and via sophisticated displays, such things as pre-injector emittance, the position and profile of the injected beam etc. As a general philosophy, routine measurements are restricted to key parameters with most variables maintained only on demand. Programs are generally written in high level language and the system runs under the control of a specially written executive OMNIBUS. Some 80K words of core and an impressive array of disks and magtape are used.

2.1.2 7^{o} Beam Line

The Sigma 2 (16K + disk + paper tape) provides extensive control for a number of experimenters, each of whom is provided with a C.R.T. display terminal. The use of the manufacturer's RBM executive has enabled work to be centred on applications programs and the whole system has been readily accepted by the users.

2.2 Berkeley

Following their early experiments with closed-loop control of the inflector system, the Bevatron group now have other similar applications. Currently three small (PDP8) computers are used, each of which has a specific well-defined task (external proton-beam transport magnets, R.F. system and guide field). Although their multi-processor approach was adopted originally for reasons of economy and caution, the group is strongly in favour of designing future systems this way. Benefits of being able to tackle greater task complexity within a given time, easier extension and avoidance of ultimate saturation of a single large computer are all claimed for this approach. Inter-communication between the computers is performed via the direct memory access channels. The importance of good operator/computer interface philosophy has been appreciated from the outset.

2.3 Brookhaven

Two PDP8 computers have been used in the AGS main control room, largely for evaluation purposes and to assist in the machine studies programme. A further PDP8L is used to maintain and control the quadrupoles, R.F. and other functions of the new 200 MeV injector linac. The group is in process of replacing the PDP8's with a more substantial machine - possibly a PDP10. They maintain that computers enable better value-for-money to be obtained from the limited time available for machine studies and provide the necessary "better tools" to improve machine efficiency. Specific points considered to be of importance are:-

a) The computer needs to have access to many parameters and it needs to be large enough for interesting problems to be tackled.

b) A high level language eg FORTRAN is necessary to allow rapid and efficient programming for experimenter use.

c) An interpretive language eg BASIC may be the only way of providing adequate operator facilities.

d) A multi-user EXECUTIVE system is desirable so that studies can, within limits, be carried on simultaneously with normal machine use.

2.4 CERN

Papers from the groups concerned with the control computers on both the P.S. and I.S.R. will be presented later today, so I will not anticipate these events. There are a few additional worth-while comments that can be made.

2.4.1 C.P.S.

Fairly recently, a changeover has been made to a more sophisticated executive for the IBM 1800 and the core size increased. Even so, the new MPX (Multi-programming Executive - supplied by IBM) has limitations for efficient core usage. A separate mini-computer (Varian 620/i) is used for controlling the P.S. Booster function generator - a real-time task. The restrictions imposed by the use of assembly language programming are well appreciated and ways of providing better facilities for machine studies are being sought - possibly through the use of an interpretive language. Better operator/machine interfaces, too, are being investigated.

2.4.2 I.S.R.

In addition to providing monitoring and control functions for the I.S.R., the twin Argus 500 system is used for machine development. Experimenters using the system prepare program flow diagrams which are then coded up by professional programmers and put into the system.

2.5 LAMPF

There are historical, as well as philosophical and economic, reasons for LAMPF's adherence to having a single large computer in their control system. Building on the success of their pilot scheme (the Electron Prototype Accelerator), they are busy integrating the controls of the actual accelerator, as it is built, through the big central computer (SEL 840 - 48K) to the control consoles. It is clear that very considerable thought has gone into the design of these consoles and into operator controls generally. Prior to coupling the pre-injector and low energy stages of the accelerator to the central computer, a small (8K Data General NOVA) computer has been used very successfully for diagnostic and checkout purposes.

2.6 NAL

Unfortunately there are no papers on the control system being presented at this conference by NAL. As might be expected, the computer control system at Batavia has many interesting features representing different facets of the current state-of-the-art. Fig. 1 is an attempt to show a number of these features in a way, hopefully, not too far removed from actuality.

Particular points about the system are:-

a) The central computer does not operate in Real Time - this function is reserved for the satellites (mini's and linac Σ2).

b) The use of an interpretive language is hoped to provide the key to effective single operator working.

c) Complex operations are broken down into the basic steps by the central computer.

d) Communication to and from the central computer is in ASCII code trasnmitted serially.

e) Degraded operation, via a Teletype inputting directly to the MAC 16's, is possible as is multiple operation at several levels.

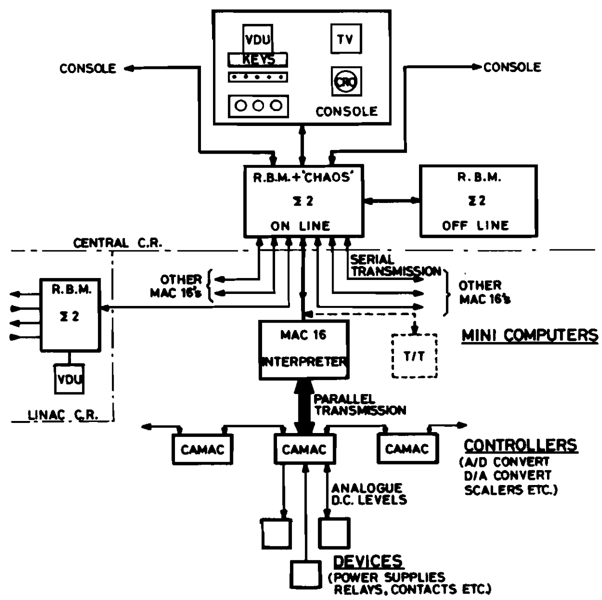

Fig. 1 NAL COMPUTER CONTROL

2.7 RHEL

There are two computer control schemes currently being supported - that on the extracted proton beam line X3 and the second (and later) one on the separated line K9, which feeds the 1.5 m H.B.C.

2.7.1 X3

The value of the system has been apparent from the start and the facilities have been extended to embrace the other extracted beam lines (X1 and X2). The system provides processed data displays, fault messages and machine performance statistics. The system is very successful and much appreciated by the operators, but it has highlighted the amount of software effort needed to support an assembly language approach.

2.7.2 K9

The K9 system, about which you will be hearing later, uses Interpretive Software and CAMAC to overcome some of the shortcomings of X3.

2.8 Radiotechnical Institute

Work has been continuing on the use of on-line computers for orbit measurement and correction - the cybernetic accelerator. The extension of the ideas to accelerators with superconducting magnets, with a view to saving expensive excess aperture, are being studied. Accelerators with final energies in excess of 4000 GeV are being talked of as being economically feasible - using the cybernetic principle.

2.9 SLAC

At present the major effort centres round integrating the working of the two control rooms through linking the two control computers (SDS 925 in the Data Assembly Building and PDP9 in Central Control Room). The effective control position is also being moved to the DAB to be near to the experimenters. The need for a comprehensive computer operating system has been realised from early on in the development of the project and a special multitask operating system has been written for the PDP9 to overcome problems of task priority.

A particularly interesting feature of the work at SLAC is the development of touch panels for operator interaction - more will be said about these later.

Little closed loop control has been accomplished due mainly to the lack of the necessary interfaces.

2.10 SEN & TRIUMF

These two cyclotrons will have computer control systems very like those, to which we are accustomed, for synchrotrons and linacs. A few months ago SEN took delivery of their IBM 1800, which will use a PDP8S as a satellite. TRIUMF now have at least 3 of their Data General Supernova Computers.

3. State of the Art

From the work just noted, I believe that one can discern some form of vague pattern. The fact that the pattern has taken so long to emerge does not imply that folk have been working aimlessly but rather that sufficient groundwork has only now been carried out. One of the major differences between computer control for accelerators and that for some process plant is the high degree of flexibility required for the former. An accelerator control system is seldom, if ever, in a fully static state. Improvements and additions are frequently required and these have to be incorporated without impairing the operation of the accelerator. We are only just learning how to achieve this, through a modular approach to both hardware and software. One of the emerging patterns is the similarity between the software and hardware systems and the improving possibility of choice between the two for solving specific problems.

In spite of this similarity, it is convenient for the purposes of this talk to consider hardware and software aspects separately.

3.1 Hardware

The continuing development of more complex integrated circuits means that more and more possibilities are open to the control engineer. Signals tend to be digital rather than analogue and very compact, cheap and reliable equipment is possible. Very compact, mass produced mini-computers are now available for less than the cost of a reasonable oscilloscope. These developments are being exploited in accelerator control systems to provide better system capabilities and performance at no greater cost. Because it illustrates many points, reference will be made, from time to time, to Fig. 1.

3.1.1 Real-Time and Mini-computers

It is fairly clear that the more the control system, as a whole, is involved with real-time matters then, in general, the more data has to be moved about from one place to another. High speed, long distance data transmission is expensive and so is avoided when it is not absolutely necessary. The use of satellite mini-components to remove the real-time load from long distance transmission systems and the central computer is certainly the current way of thinking (Fig. 1). Another good example is the Varian 620/i on the P.S. Booster[17]. The 300 GeV accelerator will also use mini-computers for this reason. Of course, a careful (and honest) separation of real-time requirements from those that can be performed more leisurely is a pre-requisite to this mini-computer application (and also to good software system design). Serial transmission (Fig. 1), between central and satellite computers, also becomes adequate with this separation.

3.1.2 Computer/Equipment Interface

Sooner or later, all control computers(mini or otherwise) have to talk directly to the equipment they are controlling. Some form of interface is needed, for example to provide A/D or D/A conversion, parameter buffering etc. etc. The possibility of using a standardised, modular system, with manual input facilities is very attractive. Not only would such a system allow rapid replacement of faulty plug-in units (module) but it would facilitate equipment development and commissioning without involving the rest of the computer control complex. Although CAMAC, the interfacing system widely used for physics experiments has been around for a number of years, it is only now that availability is becoming adequate and sufficient control-oriented modules have been designed to allow its serious consideration for accelerator control systems. Many laboratories (eg. NAL, LAMPF & RHEL) already have CAMAC in control systems - or are actively persuing the possibility. I feel sure this trend will continue with increasing momentum.

3.1.3 Computer/Operator Interface

In any control system, presentation of information to the operator and means of inputting his requests are vital issues. It is not surprising, therefore, that much thought is being given to operator interfaces. Three examples, recently reported, indicate the techniques currently available.

a) Touch Panels

Interaction with computer generated C.R.T. displays, via "light pens" is well known. It tends to be expensive and, personally, I find a bit awkward. Light pens can only be used with refresh-type displays. Touch panels which can be used with any C.R.T. display using the interruption of surface waves [1] or infra-red beams [3] for location are attractive alternatives, currently being developed.

b) Visual Display Units (V.D.U's)

C.R.T. units complete with local refresh memory and keyboard are now important parts of many Time Sharing Computer Systems. Versions of these V.D.U.'s, possibly including a mini-computer and some even with multicolour displays are appearing in accelerator control systems [4].

c) Incremental Knobs

One problem, with keyboard input of parameter values, is that the operator loses his sense of "feel". The use of a knob coupled to an incremental encoder, which can be "hooked" to a parameter or set of parameters via the computer, is an elegant solution to the problem [5]. The encoder fills or empties an up/down counter (one of the new integrated circuits previously mentioned), that is read every 100 ms while the knob is being turned. The rate of change is proportional to the speed of turning the knob.

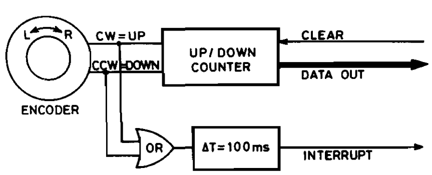

Fig. 2 Incremental Knob

3.2 Software

The fundamental problem associated with computer control software is really one of turn-round. The machine operator and physicist need ways of trying out new ideas quickly. It is no good telling them to "come back next week and try the new program you ordered". Developments over the last year or so have gone a long way towards solving this problem. Fig. 3 is useful in discussing the build-up of computer control programs, it also draws parallels with modular hardware. For the sake of this talk I want to assume that the subroutines (for example a CAMAC drives routine) are provided and that the difference between sub-programs and applications programs is just a matter of the degree of complexity.

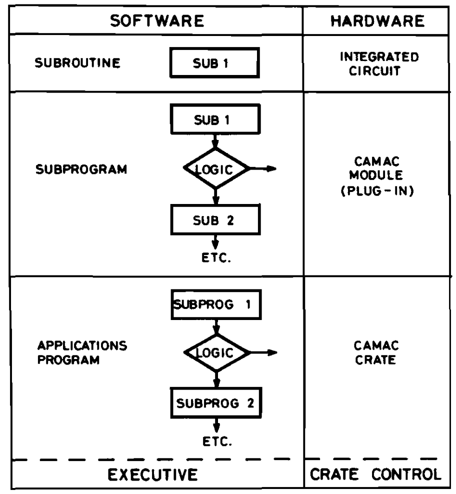

Fig. 3 Software/Hardware Hierarchy

The solution to the turn-round problem lies in being able to establish the subroutine or sub-program links and to introduce new applications programs quickly and in a flexible way. Adequate computer operating systems and executives are really only now appearing and the good ones are helping enormously. One only has to look back to see a correlation between the quality of manufacturers operating system and the rate at which the computer control system "got off the ground".

Most of us appreciate the problems of linking subroutines via assembly code and loading the resultant programs via rudimentary operating systems - and of writing good operating systems. The ability to use a high-level language, eg. FORTRAN, for linking and the availability of good foreground/background monitors has speeded up program implementation very considerably. This is still however an off-line approach.

The use of interpretive software provides what can be thought of as an on-line approach. Interpreters work quite differently from assemblers or compilers in that no object code is generated which has to be loaded into the computer before running. The source code is interpreted directly and the subroutine linkages made on-line. This means that direct commands can be typed in as soon as the idea has been conceived. As an example:-

```
* F N=1,3;T N,FDVM(N),!   - Operator input

 1=    329.4         )
 2=    671.6         ) - Computer output
 3=    154.0         )

*                         - waiting for more input
```

The penalty one pays for this on-line programming is execution time. If the interpreting time can be reflected into the operator or hardware time scales - which it can if the real-time functions are handled separately, the speed is more than adequate. The development of a disk-based interpreter capable of linking assembly code, or interpretive code program modules I believe could well be one of the most important developments ever in the field of accelerator computer control.

4. Future Outlook

It's a brave man who tries to predict the future, but I will make some comments on what I believe might happen.

Most people are now building their second, or even third, accelerator computer control system and sufficient operator experience is available to provide good practical feedback of what is needed. This will spur on the development of good operator interfaces and adequate overall control philosophies.

Complex operations will be easy to program in interpretive language. Multi-user, multi-priority interpretive systems will be developed which will permit normal running and machine study periods to overlap considerably. Even more efficient use of core space will be possible resulting in cheaper control systems and smaller computers.

Many more computer functions (eg. interpreter subroutines) will be implemented in hardware and interpreter speeds increased. We could eventually get a hardware interpreting computer for control purposes. Some of these features could provide improved facilities for the big computers.

I am very optimistic of a lively future for computer control. The time is now past when people doubt the value of a computer in a control system at all !

5. Acknowledgements

Sincere thanks are due to members of computer control groups everywhere in the accelerator world for helpful discussions and information.

6. References

There is neither time nor space to provide detailed cross references throughout the text. However general reference can be made to:-

1) Proceedings 1971 Particle Accelerator Conference Chicago 1-3 March. IEEE Trans. Nuc. Sci. Vol.NS-18 No. 3.

2) Proceedings 1970 Proton Linear Accelerator Conference, 28 Sept - 2 Oct. National Accelerator Laboratory, Batavia, Illinois.

6.1 Specific References

3) E.M. Mott, Rutherford Laboratory, Private Communication.

4) D. E. Young, National Accelerator Laboratory, Private Communication.

5) D. R. Machen, Los Alamos Meson Physics Facility, Private Communication.

DISCUSSION

J.H.B. MADSEN : The minicomputer was said to be a low-price device on the order of the price of an oscilloscope. To integrate the minicomputer into an overall system, the final price including software may well be five times higher.

J.T. HYMAN : Two points can be raised in answer :
i) Many software problems (and hence cost) arise from multiple use of computers. Minicomputers are essentially dedicated devices.
ii) Frequently the programming costs can be shared between several minicomputers. I feel that the factor of five times the hardware cost is excessive for the software.

R. KEYSER : It appears to me that the big advantage of Interpreters is that they combine the functions of compiler, editor and loader. This is especially important for small computers without a disc since it avoids continuous loading-in of programs from paper tape. However, on larger computer systems with a disc, this problem disappears. Do you consider that on the larger systems there is a significant advantage of an Interpreter over an editor-compiler-loader suite of programs ?

J.T. HYMAN : I agree that larger computers with a good disc-based operating system do provide easier working with high-level languages. However, there are advantages to be gained from an interpreter, particularly in a disc system, as demonstrated in the work at RHEL. The ability to run part programs, even single lines of program under the interpreter is most valuable and greatly facilitates "on-line" programming using direct commands.Clearly, interpreters are not the only way of doing things but they represent a new approach that I am sure will have a great future.

L.C. TENG : It is true that at the moment the linkage between our MAC-16's and the Sigma-2 is not yet fully developed. The Sigma-2 is used mainly for message switching and transmission and has no higher level language capability. As an interim measure we recently provided a telephone line data-link between the Sigma-2 and a PDP-10 equipped with time-sharing peripherals. The operator can now write a data processing program in, say, FORTRAN. The program is resident in the PDP-10. The accelerator data can be transmitted from the Sigma-2 to the PDP-10. After having processed in the PDP-10, the results are transmitted back to the Sigma-2 either for display or for transmission to the MAC's for execution. This data link is of course, off-line and not on real time. Eventually we do plan to implement the hierarchy design that was shown in the slide.

G. SCHAFFER : There is one aspect of computer control that has not been mentioned and which is, I believe, very important. In a large project, there are many types of people involved (engineers, mathematicians, accelerator physicists, experimental physicists, theorists, etc.) who bring many widely differing and complex problems to those who are designing the computer-control system. The general managerial (mainly psychological) tasks involved in co-ordinating men with software and hardware are not trivial.