16 Computer Control

M.L. Roberts

Woods Hole Oceanographic Institution, Mail Stop No. 8, Woods Hole,
MA 02543, USA
mroberts@whoi.edu

16.1 Introduction

In the past two decades, the greatest improvement to the performance and ease of operation of electrostatic accelerators has undoubtedly been the development and implementation of computerized control systems. In the "old days", control of an electrostatic accelerator and associated components was accomplished through a large central console containing a massive collection of knobs, switches, meters, dials, and indicator lights. This central console was often located some distance from the accelerator, which necessitated long (and hence expensive) control cable runs that made the system susceptible to ground loops and electromagnetic interference. Each element in the accelerator system was typically controlled by a custom-fabricated chassis in the control console and this individuality increased costs, caused difficulties in repair and maintenance, and created a system not readily amenable to change. These major difficulties aside, however, perhaps the biggest disadvantage of these "knob-based" consoles was the fact that start-up of a typical accelerator system (or even changing from one set of parameters to another) could require the assistance of one or more skilled operators and require hours of "tuning" and/or "retuning". Modern, properly designed and implemented computer control systems have alleviated many of these issues.

An old "knob-based" console for accelerator control is shown in Fig. 16.1. Figure 16.2 shows the operator interface of a modern, computer-controlled accelerator system. The difference is striking, given that the complexity and number of elements controlled in each accelerator system are similar. Comparing the two photographs, one can begin to understand that a computerized control system is less expensive to implement, more reliable, more precise, less expensive to operate, easier to modify, more flexible in the rapid shift from one set of parameters to another, and more capable than a "knob-based' system. The "knob-based" system is only more impressive in scale.

16.2 Software and Hardware

A large array of software and hardware is available and appropriate for use in an accelerator control system. Because new technology, new products,

Fig. 16.1. A "knob-based" central control console used to control the High Voltage Engineering Corporation model FN tandem accelerator and associated components at the Triangle Universities Nuclear Laboratory, Duke University, Durham, NC. The photo is circa 1970 and courtesy of Chris Westerfeldt, TUNL, Duke University

Fig. 16.2. A satellite computer used to control the High Voltage Engineering Corporation model FN tandem accelerator and associated components at the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory. Essentially the entire accelerator system can be controlled from a single computer screen. Photo courtesy of William Fields, CAMS, LLNL

and new software are continuously being developed, any detailed discussion of computer control hardware and software is almost instantly out of date. Nevertheless, a generalized description of some of the software and hardware typically found in an accelerator control system is worthwhile.

Figure 16.3 shows a generalized computer control system. The operator interacts with software on a computer that in turn communicates to a device interface. The device interface contains all the analog and/or digital inputs and outputs (I/Os) needed to control the particular device(s). A device is any of the multitude of power supplies, solenoid valves, beam profile monitor(s), oscilloscopes, etc. needed to operate the accelerator. In small accelerator systems, with only a few devices to control, the control system may have only

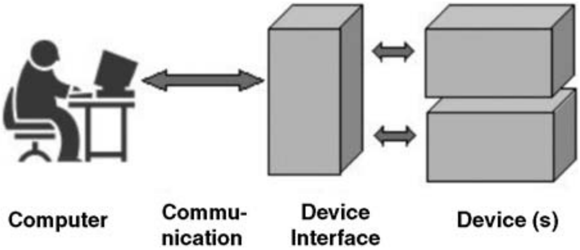

Fig. 16.3. A generalized computer control system

one device interface, which may in fact be directly embedded in the computer. Large accelerator control systems, with hundreds of devices, may have multiple computers and multiple device interfaces distributed throughout the accelerator facility.

Several software packages are suitable for use in an accelerator control system, and only a few brief comments can be made about these very complex software programs. The majority of accelerator laboratories that have upgraded their infrastructure from a "knob-based" to a "computer-control" system seem to have used either LabVIEW [1] or EPICS [2]. LabVIEW is suitable for small to medium-sized accelerator systems, is cross-platform compatible, and uses a graphical programming language that is relatively easy to learn. EPICS, or Experimental Physics and Industrial Control System, is primarily used on large accelerator systems. EPICS requires considerable computer expertise to implement, and is specially designed for high-bandwidth, real-time networking applications in which tens or even hundreds of computers are linked together. Two other software packages that have been used in accelerator control applications are InTouch [3] and Vsystem [4]. The two largest commercial manufacturers of electrostatic accelerators, National Electrostatics Corporation and High Voltage Engineering Europe, use control software developed in-house [5, 6].

Various communication schemes between the computer and the device interface are frequently found in accelerator control systems. These include copper cable (i.e., the General Purpose Interface Bus (GPIB), RS-232, RS-485, etc.), fiber optics (glass or plastic), and networks (usually a local area network but occasionally the Internet). Copper cable, especially GPIB, can offer high data transfer rates. Distances are limited and electromagnetic interference can be a problem. A network can communicate over long distances but can be limited to low data transfer rates. Accordingly, many networked computer control systems have computers embedded within the device interface. The embedded computer takes care of local, speed-critical tasks and only system changes are transmitted back to the main control computer. Fiber-optic communication offers good data transfer rates, works over moderate distances, and is relatively immune to electromagnetic interference. Furthermore, many accelerator laboratories wish to control various devices at the terminal of the accelerator or at ion source potential. Fiber-optic communication is ideal in situations requiring high-voltage isolation.

The device interface is essentially the interconnect between the computer and the particular device(s) that need to be controlled. One of the more popular device interfaces is Computer Automated Measurement and Control (CAMAC). CAMAC devices were first developed in 1969 and were designed for use by the high-energy physics data acquisition community. Since many accelerators were (and are still) being used for high-energy physics research, it is only natural that these devices would find their way into accelerator computer control systems. Many manufacturers [7] make various CAMAC modules. Typical modules include analog outputs (to control a power supply or device), analog inputs (to read back voltages or currents), digital outputs (to control a solenoid valve or switch), digital inputs (to read back the status of a solenoid valve or switch), timing generators, counters, and waveform recorders. Increasingly, many feel that CAMAC is becoming obsolete technology. Some CAMAC users are switching to VME (Versa Module Europa) or VXI (VME eXtensions for Instrumentation). Most manufacturers of CAMAC modules also make VXI modules. Compared with CAMAC, VXI offers better immunity from electromagnetic interference. Unfortunately, VXI devices tend to be more expensive and less densely packed than comparable CAMAC modules.

Device interfaces designed specifically for computer control of accelerator systems are also available. Group3 [8] has a line of products in which fiber optics are used to link a series of small, distributed modules. A module may contain one or more analog outputs, analog inputs, digital outputs, digital inputs, stepper motor controllers, communication ports, etc. One Group3 module even has provision for an embedded PID (proportional–integral–derivative) control algorithm that can be useful for closed-loop control of various devices (e.g., a momentum-analyzing magnet). A Group3-based control system is easily expandable, and the fiber-optic communication provides high-voltage isolation and good noise immunity. Overall, Group3 control products have found wide acceptance in many accelerator laboratories.

Other manufacturers also make instrumentation useful in accelerator control systems. Besides LabVIEW, National Instruments makes a diverse array of device interfaces, including digital oscilloscopes and motion controllers that have found use in control systems. Industrial control system hardware such as programmable logic control (PLC) has also been used in some accelerator control systems. Two PLC brand names are MODICON [9] and Allen-Bradley [10]. PLC technology is simple, inexpensive, and robust but can lack the control precision demanded in most accelerator operations.

16.3 Operator Interface

More important than the choice of software and hardware is the manner in which accelerator personnel interact with the control software. A poorly implemented interface can outweigh all possible positive features of a computer control system. A good interface can greatly enhance the usefulness of a computer control system. What makes a good computer control system, however, is somewhat dependent upon the eye of the beholder. Accelerator operators want a control system with a quick response, and need tools to analyze ongoing operations and make correlations between parameters and measured values. Maintenance personnel want to monitor magnet currents and the voltages of the power supplies, and to have tools that provide information for analyzing and investigating problems. Computer support personnel have their own requirements to monitor system performance and error logging. Accelerator users typically want an on/off button. The end result is that the control system must contain hardware and software components that allow the users of the accelerator to control the accelerator system in the most efficient and effective manner possible.

The best accelerator computer control systems have a minimum of display windows and are graphically based (i.e., the use of tables of parameters is avoided). In small accelerator systems, the entire system can often be displayed on a single computer window. Nonessential information such as setup parameters, maintenance diagnostics, and nonroutine procedures are not continuously displayed, and are made accessible from separate (and usually hidden) computer windows. It is often helpful to have a flowchart or basic outline of the accelerator and beam transport elements. This outline helps the infrequent or novice user understand the flow of the beam and the spatial relationship of the various devices. Faraday cups and vacuum valves can be inserted or retracted at the push of a mouse button. Power-supply settings can be changed by clicking on a device and entering a new value or by assigning the device to a control knob. Error conditions (such as an out-of-range power supply) can be indicated by having the device icon change color or shape. A brightly colored error indication will draw the eye much faster than scanning a list of parameters looking for differences. In addition, provisions should be made so that previous set points can be retrieved and current set points logged and saved for future retrieval. If anything can be sequenced or automated, it should be.

The response time of the accelerator computer control system should also be considered. Early computerized control systems often displayed a noticeable lag between when a computer button or knob was pushed or turned and when the physical device actually responded. This slow response was annoying and made beam tuning difficult. The increased speed of modern computers has largely solved this problem. However, consideration should still be given to leaving high-frequency devices such as beam profile monitors and Faraday cup current measurements outside of the computer control system, with only the control of such devices in the control system.

Finally, control of items involving either personnel safety or instrument protection should be independent of the computer control system. Such items include but are not limited to radiation interlocks, vacuum interlocks, and high-voltage interlocks. Primary control of such items should be through hardwired systems. It is perfectly reasonable to monitor or back up such systems with the computer control system, but a computer must never be the primary system when safety is involved.

16.4 Special Algorithms

Various special routines or algorithms have been developed that allow the users of an accelerator to control the accelerator system in the most efficient and effective manner possible. Although the exact details of these algorithms will vary with the details of the individual control systems, the general principles described should be useful in many accelerator computer control systems. These routines include "flat-topping", "scaling", "conditioning", closed-loop control, and auto-tuning.

Output from a typical so-called "flat-topping" routine is shown in Fig. 16.4. "Flat-topping" involves slewing a selected optical element over

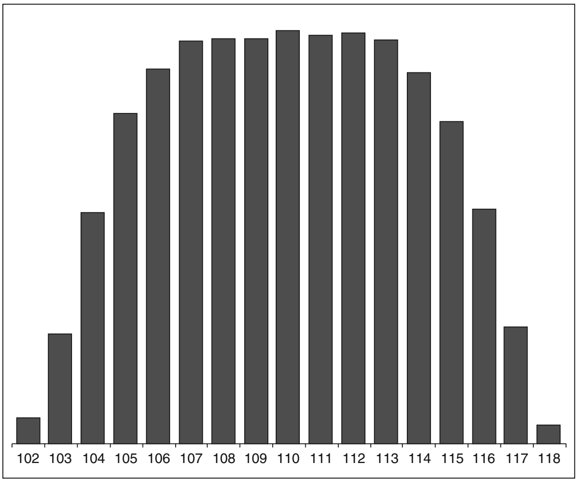

Fig. 16.4. Output from a "flat-topping" routine. The x-axis is the device set point varied over some user-defined range. The y-axis is an arbitrary measured parameter (in this case a Faraday cup current). "Flat-topping" allows the operator to set a device in the middle of the "flat-top" region of the tuning response curve. With a "knob-based" control system the operator might inadvertently tune the device near one of the "edges'

some user-defined range and displaying the value of that element against a measurable parameter (e.g., current from a Faraday cup or counts from a detector). "Flat-topping" allows the operator to precisely set the value of a selected element to the optimum value. "Scaling" involves using basic physical formulas to "scale" the accelerator from one operating point to another. The change in operating point could be either to a new energy setting or to a new mass or both. These algorithms can be surprisingly precise and are of great use in laboratories that utilize many different types of ions and/or a broad range of energies.

Routines can be designed to aid in the "conditioning" of the accelerator to high voltages. A "conditioning" routine might involve ramping the terminal potential in a sawtooth fashion in which the accelerator terminal potential is raised by a user-defined value for a user-defined time. The terminal potential is then dropped (again by a defined value for a defined time) and the process repeated as often, and as long, as necessary to reach the desired terminal voltage. Many laboratories have found this method of conditioning more effective than a slow incremental increase in terminal potential. The computer control system can relieve the operator of this tedious and boring procedure.

The computer control system can also be used to stabilize, or closed-loop control, a device such as a bending magnet. Using a Hall probe, algorithms can be developed to adjust the output of a power supply to maintain a precise magnetic field. Since Hall probe readings are typically more precise and stable than power supply current readings, these techniques provide a more stable ion beam than what could be obtained if one were to rely only on the internal stability of the power supply. In any closed-loop system, however, care should be taken to avoid control offsets and oscillations. Various texts on control loops are available [11, 12].

Finally, some accelerator laboratories have implemented routines to automatically tune beams. The accelerator mass spectrometry (AMS) group at the Vienna Environmental Research Accelerator, University of Vienna, Austria has developed a tool that maximizes a measurable parameter (i.e., a Faraday cup current) by adjusting accelerator parameters (e.g., steerer voltages, magnet currents, and slit positions) [13]. Such routines are valuable in maximizing ion transmission, especially in cases where apertures are narrow and "flat-top" transmission is difficult to obtain. High and reproducible ion-optical transmission is essential in AMS measurements since beam losses can directly influence measured isotope ratios.

16.5 Summary

Given changing technology, the large array of available software and hardware, and the personal preference of the individuals involved, it is almost certain that no two computer control systems for electrostatic accelerators are exactly the same. Nevertheless, most accelerator control systems use similar hardware and have similar design philosophies. Compared with a "knob-based" system, computer control systems are less expensive to implement, more reliable, more precise, less expensive to operate, easier to modify, and more flexible in the rapid shift from one set of parameters to another. Furthermore, a computer control system has expanded capabilities that cannot be readily achieved by a "knob-based" system. More information about computerized control systems is available from the above-referenced manufacturers or a variety of reports from specific accelerator laboratories [14–19].

References

1. LabVIEW, National Instruments Corporation, Austin, TX, USA
2. EPICS, or Experimental Physics and Industrial Control System, is also the name of the collaboration of organizations that were and are involved in the software's development and use. Los Alamos National Laboratory, Los Alamos, NM, USA, and Argonne National Laboratory, Argonne, IL, USA originally wrote EPICS jointly
3. InTouch®, Wonderware/Invensys Systems, Lake Forest, CA, USA
4. Vsystem®, Vista Control Systems, Inc., Los Alamos, NM, USA
5. National Electrostatics Corporation, Middleton, WI, USA has developed a computer control software package called AccelNET. Details can be found in "Automated accelerator controls for a 3 MV tandem Pelletron", R.D. Rathmell, R.L. Kitchen, T.R. Luck, M.L. Sundquist, Nucl. Instr. Meth. Phys. Res. B **56/57** (1991) 1072
6. High Voltage Engineering Europa B.V, Amersfoort, The Netherlands has developed in-house a dedicated MicrosoftWindows-based computer control software program
7. There are many manufacturers of CAMAC devices, including Kinetic Systems Company, LLC, Lockport, IL, USA; Joerger Enterprise, Inc., East Northport, NY, USA; BiRa Systems, Inc., Albuquerque, NM, USA; and CAEN S.p.A., Viareggio, Italy
8. Group3 Technology, Auckland, New Zealand
9. MODICON, Schneider Electric, Groupe Schneider, North American Division, Palatine, IL, USA
10. Allen-Bradley®, Rockwell Automation Control Systems, Milwaukee, Wisconsin, USA
11. K.J. Åström, T. Hägglund, *PID Controllers: Theory, Design, and Tuning*, 2nd edn. (January 1, 1995), Published by The Instrumentation, Systems, and Automation Society, Research Triangle Park, NC 27709 USA
12. A. Datta, M.-T. Ho, S.P. Bhattacharyya, *Structure and Synthesis of PID Controllers*, Springer Berlin, Heidelberg, 2000
13. P. Steier, S. Puchegger, R. Golser, W. Kutschera, A. Priller, W. Rom, A. Wallner, E. Wild, Developments towards a fully automated AMS system. Nucl. Instr. and Meth. B **161–163** (2000) 250–254

14. R.D. Rathmell, R.L. Kitchen, T.R. Luck, M.L. Sundquist, Nucl. Instr. Meth. Phys. Res. B **56/57** (1991) 1072
15. M.L. Roberts, T.L Moore, Nucl. Instr. Meth. Phys. Res. **56/57** (1991) 1080
16. J.R. Lutz, J.C. Marsaudon, Nucl. Instr. Meth. Phys. Res. A **328** (1993) 113
17. T.M. DeTurck, D.J. Treacy Jr., D.L. Knies, K.S. Grabowski, C. Knoll, C.A. Kennedy, G.K. Hubler, in: J.L. Duggan, I.L. Morgan (Eds.), Conference Proceedings 475, American Institute of Physics Press, New York, 1999, p. 668
18. N. Akasaka, A. Akiyama, S. Araki, K. Furukawa, T. Katoh, T. Kawamoto, I. Komada, K. Kudo, T. Naito, T. Nakamura, J. Odagiri, Y. Ohnishi, M. Sato, M. Suetake, S. Takeda, Y. Takeuchi, N. Yamamoto, M. Yoshioka, E. Kikutani, Nucl. Instr. Meth. Phys. Res. A **499** (2003) 138
19. D.S. Barton, S. Binello, W. Buxton, T. Clifford, T. D'Ottavio, H. Hartmann, L.T. Hoff, R. Katz, S. Kennell, T. Kerner, J. Laster, R.C. Lee, A. Marusic, R. Michnoff, J. Morris, B.R. Oerter, R. Olsen, J. Piacentino Jr., J.F. Skelly, Nucl. Instr. Meth. Phys. Res. A **499** (2–3) (2003) pp. 356–371