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THE USE OF MINICOMPUTERS IN PARTICLE ACCELERATORS*

by

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ABSTRACT

A substantial number of the world's research laboratories in low, medium, and high energy physics have been among the earliest users of minicomputer data acquisition and control systems. A decade ago, the commercially available minicomputers were put to use gathering data from physics experiments using particle beams from accelerators. As early as 1965, engineers and physicists at several North American accelerator laboratories were installing minicomputer-based control systems for the purpose of automating particle-beam transport lines. Since that time, the use of minicomputers for special instrumentation, data acquisition, and supervisory control has mushroomed throughout the accelerator world.

The application of minicomputers to the accelerator beam diagnostics, experimental interface development, accelerator structure tuning, magnet field mapping, ion source operation, nuclear instrumentation, and data handling as practiced at LAMPF,** and other accelerator laboratories throughout the world, will be related in this paper.

MASTER

INTRODUCTION

A particle accelerator facility can, in a general way, be logically divided into two physical areas - the area for production and acceleration of a particle beam (electrons, protons, etc.) and the area for utilization of the particle beam (commonly called the experimental area). This paper presents a survey of the use of minicomputers in the operation, control, and instrumentation of particle accelerators related to the production and acceleration of particle beams. Also mentioned are applications involving the acquisition of experimental area data. The acquisition and reduction of experimental data has received considerable attention at a recent conference on computers in nuclear physics.¹ However, the computer systems now in general use in accelerator experimental areas can seldom be classed as minicomputers. The paper contains a brief historical perspective of minicomputers in accelerator applications, then summarizes the use to which minicomputers have been put during the construction and operation of LAMPF. Applications of Nova and Super Nova computers to proton beam diagnostics, experimental interface development and evaluation, accelerator structure tuning, magnet field mapping, and ion source operation will be described. Also, applications of PDP-11/05, /10, /20, and /45 computers to nuclear instrumentation testing, development, and data handling will be presented. In addition, the relevant development of minicomputer applications in other physics laboratories will be cited; the use of minicomputers in the accelerator world is by no means unique to one facility.

A research facility can, more easily and with less concern toward the dollar return, adapt a rapidly expanding electronics and minicomputer technology to its process. This has been the case with many particle accelerator facilities throughout the world. As particle accelerators have grown in size, complexity, and sophistication, the need for more sophisticated acquisition and reduction of data related to their operation has also grown. This need has precipitated the liberal use of small computers for on-line data handling, equipment control, diagnostics and instrumentation, off-line hardware and software development, and maintenance tasks.

HISTORICAL PERSPECTIVE

The use of minicomputers in on-line control, data handling, and related instrumentation of a particle accelerator first received serious consideration in the 1965 design study for a 200-GeV proton synchrotron.² A prototype control system, based upon the 200-GeV design study, was initiated at the Lawrence Berkeley Laboratory (then the Lawrence Radiation Laboratory) of the University of California, to investigate on-line computer control. The system was built around a Digital Equipment Corporation (DEC) PDP-5 computer and effected closed-loop digital control of the Bevatron[†] injection transport elements.³⁻⁵ Concurrent to the early work at Berkeley, engineers at the Stanford Linear Accelerator Center were assembling a computer system to provide on-line control of transport elements in their beam switchyard area.⁶ Centered around an XDS-925 computer with specially designed interfaces, the system monitored and

recorded data channels and set and controlled magnet currents and mechanical devices. Extensive software supported an operators console and a data link to the experimenters areas. At about this same time, the proposed large scale computer control system of the LAMPF accelerator led to the application of a small computer control system on an electron prototype of the final accelerator.⁷⁻⁹ This system was based on a Systems Engineering Laboratory 810A computer which supported an operators console in addition to doing control and data handling. The computer was obtained essentially without a software operating system and so required extensive system programming as well as the required applications programs.¹⁰ These early efforts pointed out the necessity for a balanced approach involving programming, computer and interface hardware, instrumentation hardware, and a knowledge of the process to be controlled.

The later third of the 1960's saw a great proliferation of small and medium-sized computer systems applied to specific accelerator tasks both in the U. S. and in Europe. An IBM-1800 was put on-line at CERN in Geneva, Switzerland, to provide beam emittance measurements for accelerator studies on the 28-GeV Proton Synchrotron (CPS) and to provide set-up parameters for machine operation.¹¹ While in this country, the control computer at the Argonne National Laboratory Zero Gradient Synchrotron (ZGS), a Control Data 924-A, was used to reduce data and produce a tune profile for the accelerator.¹² This data allowed the operators to adjust the guide-field correcting magnets in the ring to obtain any desired tune-up in just a few minutes. These and other instrumentation efforts opened the door for on-line control of accelerators and beam lines. Further effort at the Lawrence Berkeley Laboratory involved a PDP-8 computer

system to provide programmed and closed-loop control of beam transport magnets on the Bevatron External Proton Beam.¹³ The Bevatron computer system has more recently evolved to several PDP-8 computers, each doing specific tasks throughout the complex.

Again, at the CERN Laboratory in Europe, efforts were also being made to control a beam ejected from the CPS with the computer control system.¹⁴ This program included efforts to optimize the ejected beam position on an external target. In what might be considered a natural evolutionary process from control of single beam lines to control of an experimental area, the group at the ZGS applied an XDS Sigma 2 computer to the experimental area control system; and the isochronous cyclotron at the University of Maryland integrated an Interdata Model 3 computer into their control system.^{15,16} Then in 1970, the cyclotron group at the University of Indiana developed a control system around an XDS Sigma 2 computer to aid in the operation of their facility.¹⁷

More recently, at both the Brookhaven National Laboratory (BNL) in New York and the National Accelerator Laboratory (NAL) in Illinois, minicomputers have been incorporated into specific areas as satellite systems to larger computer control systems.^{18,19} At BNL a PDP-8 has full supervisory control and data acquisition capability on the 200-MeV linac injector for the 28-GeV Alternating Gradient Synchrotron (AGS). A link to a PDP-10 gives this minicomputer consideration computational capability. At NAL the use of the Lockheed MAC-16 minicomputer as a satellite to their main control computer in the booster and main ring systems has provided a powerful and flexible system for control and monitoring of that facility.

Most recently, the Canadian Tri-Universities Meson Facility (TRIUMF) in Vancouver (a 500-MeV synchro cyclotron) will be controlled through the use of several Nova computers in a satellite configuration about a main control computer.²⁰

The early efforts in the application of computer control to particle accelerator equipment were based on what were then called "small" computers which, although physically much larger, had about the same capabilities as today's "minis" in terms of core storage, peripheral operation, and software support. Through these efforts, the accelerator community developed an appreciation of the thoroughness and discipline necessary to successfully implement computer control of their equipment. They also developed the hardware and software techniques essential to the computer control of the very specialized equipment used in accelerator instrumentation and control. The added flexibility of a programmable element in the control system proved to be a tremendous asset to the constantly changing nature of a research facility. This experience has led to the implementation of computer control in virtually every large accelerator installation in this country and in Europe; however, many of these applications fall outside the scale of minicomputers. As it became necessary to place more hardware under computer control and as the availability of low-cost minicomputers increased, their use in accelerator installations has grown as satellites to the central control computer and as independent processors performing special tasks.^{21,22}

MINICOMPUTER APPLICATIONS AT LAMPF

The successful application of computer control to the Electron Prototype Accelerator at LAMPF stimulated the application of computers to other areas of control and data handling. The various applications that arose, although widely different in their natures, resulted in similar computer system configurations. The general configuration is shown in Figure 1 with more or less of the equipment being used in the different systems. Before describing the individual applications, a few general comments are in order. The selection of a computer for the first few systems depended as much on availability and cost as any other criteria. Based on the desire for compatibility, a change in computer manufacturers was not made until there was an obvious need for several systems with different performance criteria. The hardware configuration of the computers used in the various systems is shown in Table I. The repeated design of special interface hardware for each of the early systems motivated the acceptance of the CAMAC standard as a means of interfacing computers to instrumentation and control equipment.²³ Most of the required input-output functions are commercially available in CAMAC modules, which greatly simplifies the implementation of small data acquisition and control systems. The CAMAC standard is becoming an accepted means of computer interfacing throughout the accelerator world and is also being investigated for industrial applications.^{††}

(FIGURE 1 AND TABLE I SHOULD BE INSERTED HERE)

The software approach to the first systems was to write a minimum operating system and develop applications programs using assembly language. However, as the number of users of the systems increased, the need for a higher-level language (FORTRAN) became obvious and the use of manufacturer-supplied operating systems was adopted. Specific control and data acquisition programs were developed in assembly language and provided to the users as FORTRAN subroutines. These techniques proved to be fairly successful in the various applications described below.

Proton Beam Diagnostics at 750 KeV and 5 MeV

One of the earliest uses of a minicomputer at LAMPF was a data acquisition and control system to perform low-energy beam diagnostics.²⁴ The accelerator was commissioned in several phases. During the early stages of equipment turn-on, LAMPF engineers and physicists did not have the use of the computer control system presently operational. The prospects of laboriously determining accelerating structure and the low-energy beam parameters with conventional instrumentation and manually reducing the data was not attractive. The successful application of a Sigma 2 computer to similar problems at NAL stimulated the implementation of a minicomputer system to perform beam diagnostic functions.²⁵ The system, built at LAMPF around a Data General Nova computer, performed measurements of fundamental beam parameters such as emittance, profile and momentum-spread at beam energies of 750 KeV and 5 MeV. The hardware and software required to perform these measurements are detailed in Reference 25.

The computer, with the interface rack and peripheral devices, is shown in Figure 2; the low energy beam line can be seen in the background.

The 16-bit computer was obtained with a real time clock (RTC), power fail safe and direct memory access (DMA) logic, 16-level interrupt capability, and 8192 words of core storage. A teletype provided the basic operator command functions. Special interfaces were designed for the storage display scope, shaft encoders for positioning mechanical actuators, and the control and data system hardware. The software package consisted of the "operating system," hardware test routines, a debug program, and the beam diagnostics routines. The operating system is a group of stand-alone I/O subroutines that can be called by application programs for driving the peripheral devices. The hardware test routines were found to be essential to determine proper equipment operation and to provide a reference for the beam measurements. The operator interaction with a running program was provided by switches which were serviced by interrupt routines for stopping, restarting, or modifying a data taking operation.

(FIGURE 2 SHOULD BE INSERTED HERE)

The beam diagnostics system was assembled over a six-month period and used in diagnostics measurements for two years before its function was incorporated into the ion source control system described below. The system was designed for ease of experimenter operation. The use of a Nova assembler on a CDC-6600 computer, accessed through a remote terminal, aided off-line assemblies and kept the Nova computer available for on-line control rather than program development. All programming was done in assembly language, and the lack of a higher-level language did not prove to be a hardship on the limited number of system users. The storage scope, used to display the results of the measurements, provided

the experimenter with essentially real-time analysis of the beam parameters. Since being removed from service, this system has been used to develop mathematical techniques for data processing in minicomputer systems.

Interface Hardware Evaluation with Minicomputers

The history of computer-aided experimental physics data acquisition contains many examples of the use of special-purpose, non-reusable interface hardware. In an effort to evaluate the concept of general-purpose, reusable interface packages for experimental data acquisition electronics, a CAMAC system was installed in place of an existing interface to an operational physics experiment. This system used a Data General Super Nova computer with 8192 words of core storage, RTC, DMA, interrupts, and hardware multiply and divide. A teletype, a storage display scope, and a magnetic tape unit provided the I/O functions for the system. A fairly extensive software operating system was written to handle the high data rates (200 000 bits/sec) expected from some of the tests. Hardware test routines, debug program, and special display and data handling routines made up the complement of the software. All the programs were written in assembly language. The overall system was designed to gather data from a 400-wire proportional chamber with auxiliary scintillator-photomultiplier tube detectors for coincidence determination and display it on the storage scope or output it onto magnetic tape. The data were acquired by scanning the detectors every 8 msec, between accelerator beam pulses. The data were sorted and valid event occurrence determined in the interface hardware

before the computer was interrupted to record the event. The results of these tests provided a measure of the different interfacing techniques. It was found that the CAMAC interface provided as good a data acquisition capability as an interface specifically designed for this application. Furthermore, the CAMAC units could be used again on other experiments. This test added much weight to the decision to adopt CAMAC as a standard interfacing technique at LAMPF.

A Minicomputer for Accelerator Tuning

The proper operation of the LAMPF accelerator requires that each of the 4962 accelerating cavities be resonant at 805.000 ± 0.01 MHz. In order to assure this accuracy, an elaborate set of procedures and measurements were developed to be used during the installation of the structure. The amount of time consumed by the measurements and the reduction of the data soon became unacceptable; a minicomputer system was implemented to aid in the data acquisition and reduction. This system used a Data General Nova computer to control the process and reduce data from the hardware used in the tuning procedure. The equipment associated with this application is shown in use in Figure 3; the 805-MHz accelerator structure can be seen in the background. Tuning is accomplished by driving the tanks at their resonant frequency of 805 MHz and pulling a small metallic bead through the cavity. A measure of the perturbation in the electric field caused by the bead is obtained, then a calculation is performed to determine how far off resonance the cavity is. A mechanical correction is applied to the structure to obtain proper resonance. This system was one of the smallest assembled at LAMPF. The computer had 8192 words of core

storage with DMA and interrupt capability. It was interfaced through specially designed logic to the instrumentation and control hardware and to an analog signal multiplexer with A/D converter. A teletype and storage display scope provided the operator I/O capability. The systems software was essentially available from previous applications. Control and display programs were written to run the equipment and display the results so that the proper cavity correction could be obtained. The entire system, once set up, ran with very little operator interaction during the measurement. The system provided the needed instrumentation and control functions and was instrumental in tuning the cavities that make up 787 meters of the accelerator.

(FIGURE 3 SHOULD BE INSERTED HERE)

A Minicomputer Applied to Magnet Field Mapping

Along the accelerator and in the experimental areas, electromagnets are used to focus and bend the proton beam. The exact effect that a magnet will have on the beam can only be known by obtaining a measure of the field within the volume of the magnet, i.e., mapping the field. The equipment used to perform these measurements is shown in Figure 4. The operation is based on the programmed control and data handling capabilities of a Data General Super Nova computer. In addition to the computer, the system has a paper-tape, a magnetic tape, and special interfaces to an analog signal multiplexer with an A/D converter, an integrating digital voltmeter, and control hardware to drive various magnet field probes.

The computer and associated electronics are in the rack to the left in Figure 4. This system acquires data from both quadrupole and bending magnets; in the former case the computer rotates a coil through one revolution taking data at specified intervals. The latter case generally uses a device designated as the "RAPID MAPPER."²⁶ This system moves a test coil through the field in the x, y, and z planes. The data from a rapid mapper test usually consists of from 10 000 to 100 000 data points and is written on magnetic tape for analysis at a larger computer facility. The probe positioning mechanism is in the center of the picture; a quadrupole focusing magnet is in the background. The probes are positioned and moved under programmed or operators control through commands to the computer. The software to accomplish these tasks has all been done in assembly language. The interface hardware consisted of both special units and adaptations of units developed for providing computer control of the LAMPF accelerator hardware. This equipment has been functioning for over two years and has obtained field maps for some 150 magnets of various sizes and types.

(FIGURE 4 SHOULD BE INSERTED HERE)

Ion Source Control and Low Energy Diagnostics

Two separate particle sources are presently employed at LAMPF to supply the necessary beams of ions for acceleration. A proton (H^+) source is located within the high voltage terminal of a 750-KV Cockcroft-Walton dc power supply. A negative ion (H^-) source is located within the terminal of another Cockcroft-Walton power supply of opposite polarity. H^+ and H^-

ions are accelerated to an energy of 750 KeV by high-gradient electrostatic accelerating columns and guided some 12.5 meters through separate transport channels to the entrance of the linear accelerator.

Control of each ion source is accomplished by a data acquisition and control terminal,²⁷ located within the high-voltage enclosure of each power supply. Analog and digital signals are sent across the high-voltage interface by several modulated light-beam telemetry links. Control information for each ion source originates from either Central Control or Injector Control and is processed through a satellite minicomputer system based on a Nova computer.²² The computer, an integral part of the overall LAMPF control system, also provides local display of ion source parameters on an Injector Control operators console. The computer, peripherals, and console are shown in Figure 5. In addition to ion source control, the low energy beam diagnostic equipment previously described has been incorporated into this system.

(FIGURE 5 SHOULD BE INSERTED HERE)

Under programmed or operator control, the computer obtains data from 64 channels of instrumentation and adjusts the value of 25 different variables associated with the operation of each ion source. The peripheral I/O is through a teletype, paper-tape, storage display scope, and the meters, knobs, and other indicators on the operators console, in addition to a data-link to Central Control.

The data-scan rate of the computer has been set at five per second through use of a real time clock (RTC) located within the main frame. Update of an in-core data bank and of the console displays at this rate has been sufficient for the set-point control accomplished by the system. Low energy beam diagnostics codes are run in a background mode (i.e., time shared with other, higher-priority codes). A faster scan rate is utilized for diagnostics data acquisition and control.

Local operator control is via program-serviced console switches or the teletype; displays are presented on the storage scope in addition to the computer driven console indicators. Local ion source operation is allowed only by Central Control through a transfer command action. At that time, injector operators may perform set-point control by local console switch actuation, via the Nova computer and data system electronics.

System and applications software has been done in assembly language; required code changes are loaded via the paper-tape reader. The 8192 16-bit words of core storage contain the systems programs as well as the control and console servicing routines. This system has been in service for two years and will be expanded to handle the operation of a third (polarized proton) ion source in the near future.

Experimental Data Acquisition and Beam Line Control

Results of an intensive effort to define the requirements for experimental area data acquisition at LAMPF indicated that a minicomputer would be well suited to the task.²⁸ A number of standardized systems have evolved around DEC's PDP-11 family of computers. The computers, either

11/20's or 11/45's, have been acquired with 16 384 words of core and are interfaced to magnetic disks, magnetic tapes, DECwriters, Tektronix 4010 storage displays with keyboards, and through a Microprogrammed Branch Driver (MBD) to CAMAC-packaged instrumentation and control equipment. Since there are a number of these systems, they share DECTape and paper-tape units. The magnetic tape is the principal output device used by the experimenter, and the storage scope is used for displaying pre-processed or accumulated data while the experiment is on-line. A laboratory set-up of one of these systems is shown in Figure 6.

(FIGURE 6 SHOULD BE INSERTED HERE)

In contrast to many accelerator laboratories, where a great deal of computing power may, if needed, be brought to bear on reducing experimental physics data on-line, LAMPF is constrained to utilize available large-scale computers in an off-line mode. Data taken during an experiment must be partially pre-processed and accumulated by the smaller data acquisition system and then given to the larger computers via magnetic tape transfer or off-peak data-link transfers over low-speed transmission lines. A result of this constraint dictated the selection of a rather powerful line of minicomputers, for example the PDP-11/45.

In an attempt to further increase the overall efficiency of the experimental area computer systems, each experimenter will have a data-link available to provide digital communications between his computer and the Master Communications Terminal (MCT) Computer. This machine, a PDP-11/20, will not only relay data to the large computing resources previously mentioned, but serve as a code development and equipment checkout facility. A complete complement of peripheral devices is interfaced to the MCT.

The desire for greater efficiency in the experimental data acquisition system led to the implementation of an autonomous interface device (the MBD) between the minicomputer and the CAMAC instrumentation. The MBD was designed to remove, as much as possible, the routine I/O tasks associated with a CAMAC multicrate system from the main computer.²⁹ The MBD is a minicomputer in its own right, complete with 1024 words of 16-bit semiconductor memory and an abbreviated instruction set. A powerful feature of the MBD is the capability to multiplex up to eight high-speed data channels into the single DMA channel of the PDP-11; once programmed and initialized, the MBD will operate the CAMAC system independently of the PDP-11 and provide the PDP-11 with varying amounts of pre-processed data as dictated by the experiment (two MBDs are shown on the workbench to the right in Figure 6). The CAMAC units (the middle chassis in the right-hand rack of Figure 6) house the signal multiplexers, A/D converters, binary registers, and some nuclear instrumentation.

The primary system software (exclusive of applications and MBD programs) for each experimental area computer is embodied in the Disk Operating System (DOS). DOS, as originally supplied by the computer manufacturers, expects to operate as a single-user, non-real time system. Modifications have been made to DOS to allow operation in a real-time environment, in addition to the normal single-user program management (disk handling, edit functions, assembly and/or compilation, and initialization of codes).

Most applications codes are written in FORTRAN owing to the defacto standard that FORTRAN represents. Generally, experimenters will be able to code their data reduction problems with much greater ease and speed in FORTRAN as contrasted to assembly language. Many data acquisition

(MBD) codes and peripheral device handlers have been written in assembly language. These routines are made into FORTRAN callable subroutines so that experimenters may more easily utilize the pool of codes - an approach that tends to further the concept of standardization in software systems.

In addition to the main purpose of providing high-speed data acquisition and storage for on-line experimental data, the computers will also have control of the beam line equipment for set-up and on-line adjustment of experimental parameters. The development of these systems is still under way, but it is felt that the basic hardware and software will be flexible enough to service the many uses envisioned for them.

Minicomputer Operation of a Biomedical Facility

In addition to the basic physics research to be accomplished with the accelerated particle beams at LAMPF, a radiobiology facility for research and treatment of malignancies with pion radiotherapy is being constructed. The facility consists of a transport and beam diagnostics system for the pions (created when the proton beam strikes a graphite target) and treatment rooms with all their associated instrumentation. The operation of the facility is to be accomplished with the largest of the experimental data acquisition systems.

The system includes a PDP-11/45 computer with 40 920 words of core and semiconductor storage, two 1.2 million-word disks, two magnetic tape units, and an electrostatic printer/plotter unit in addition to the DEC-writer and display scopes. Figure 7 shows the equipment in an early stage of development. The computer is interfaced to several hundred instrumentation and control channels through an MBD-CAMAC system. (The

left-hand rack in Figure 7 contains the interface hardware.) The system also services an extensive operators console whose eight-color character scope and keyboard and software assignable knobs and function buttons³⁰ are interfaced to the computer through CAMAC hardware. The first half of the control console is shown in Figure 8. The interfacing for the magnetic tape units is also contained in CAMAC.

(FIGURE 7 AND FIGURE 8 SHOULD BE INSERTED HERE)

The computer system software to support the console and the control system will exist prior to completion of the facility. However, the applications programs will be developed through the various phases of facility checkout and operation. Initially, the system must support the beam studies of the physicists who designed the pion beam transport system. It will then be used in cell culture experiments performed by biologists. The system must then support the therapists' initial experiments with animals and eventually patient treatment. Throughout these operational phases, the computer must assume more and more of the routine equipment operation and data monitoring. A full-time systems programmer is developing FORTRAN callable subroutines for equipment operation and data handling. The experimenters will develop the applications programs. The software is being written around a modified version of the manufacturers multi-tasking real-time operating system. In addition to the hardware operation, the computer system will eventually supply a large, computational, on-line, interactive program for treatment planning and will support the necessary patient record-keeping functions.

High Energy Beam Diagnostics

The most recent application of minicomputers at LAMPF involves beam diagnostics at the high-energy (800 MeV) end of the accelerator. The data rate from 12 beam profile monitors in the experimental area exceeds the capacity of the standard LAMPF data acquisition and control terminal.²⁷ Therefore, a PDP-11/10 has been obtained to operate as a satellite computer to the accelerator control system. This computer, with 8192 words of core and hardware multiply and divide, will acquire data from the profile monitors, pre-process it (filter and perform computations) and transmit the results through a high-speed CAMAC data link (300 000 words/sec) to the central control computer. There the information will be used in setting magnet currents to achieve the proper beam in the experimental area. The computer is interfaced to the instrumentation through a CAMAC system. The programming is being done in assembly language although the availability of other PDP-11's would allow FORTRAN programming.

Hardware Maintenance and Development with a Minicomputer

In support of the experimental area data acquisition systems, there is already approximately \$500 000 worth of interface, instrumentation, and control hardware. In order to facilitate the maintenance, checkout, and continued development of this equipment, a PDP-11/05 computer has been acquired and is being programmed and built into a permanent diagnostic terminal and test-stand. The computer was obtained with only 4096 words of core and a teletype for I/O. It will be programmed to exercise the MBD and CAMAC hardware in modes that will determine their satisfactory operation, help diagnose a malfunction, and aid in the checkout of new

equipment as it is acquired. Being a laboratory-based system, this equipment will also be used to train new technicians in the use of the computer hardware and software.

CONCLUSIONS

The application of minicomputers to the various areas described in this paper has provided considerable experience to the engineers, physicists, and technicians at LAMPF. This experience seems to be reflected by the activities at other accelerator laboratories. If lessons have been learned, then the most important is the thoroughness with which a computer must be integrated into a process if the application is to be successful and the full benefit realized. The task can be divided into three areas: (1) software, (2) computer and interface hardware, and (3) the process instrumentation and control equipment. Unless the application is quite small, each area requires special attention.

When only one or two people are developing programs for the application, assembly language appears to be entirely adequate. However, where a larger number of users are writing application programs, the use of a higher-level language seems to be essential. In these cases, the use of a systems programmer to develop programs callable as FORTRAN subroutines has contributed much to the success of the applications. In the software area, a continuing effort to produce standards associated with CAMAC and other control equipment is being pursued, on an international scale, as a means of reducing the required amount of systems programming.

The availability of inexpensive, reliable minicomputers has opened areas of application in accelerators where previously special-purpose logic designs were implemented. The use of minicomputers and micro-processors as autonomous controllers, in place of conventional special-purpose logic designs, has provided an added degree of flexibility to match the nature of the work in a research laboratory. We are not advocating the exclusive use of satellite autonomous controllers in all computer-based data acquisition and control systems, nor do we claim that the utility of special purpose interfaces in applications where the equipment configuration is fixed in some way cannot be appreciated. The fact remains, however, that in more flexible applications, the use of a standard interfacing technique such as CAMAC saves design time and speeds implementation of the computer system in addition to allowing reuse of the equipment in other systems. At LAMPF, the use of specially developed signal multiplexers with A/D and D/A converters and control logic packages for the accelerator control system facilitated the applications described in this paper. The equivalent of such hardware is now generally available from commercial sources and is rapidly becoming available in CAMAC modules. Still, a good deal of design and checkout time is required to make the individual logic packages function properly as an integrated system.

In the accelerator community, adapting the process instrumentation and control equipment to the computer has been the most recent area to receive adequate attention. In any research facility, the frequency with which equipment is set up and taken down makes it necessary to have the hardware ready for the computer before installation. Once the experiment is on-line, it is difficult to justify a shut-down to implement the

computer system. This requires prior planning that experimentalists in the past have been reluctant to provide. Nevertheless, conventional instrument and control equipment designers are cooperating and providing both on/off status, control signals, and measurements of process variables compatible with computer control.

If our experience provides any measure of things to come, and we think it does, then minicomputer applications will continue to proliferate in accelerator laboratories and research facilities throughout the world.

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Footnotes

- * Work performed under the auspices of the U. S. Atomic Energy Commission. (Page 1, title of paper)
- ** The Clinton P. Anderson Meson Physics Facility (referred to as LAMPF) of the Los Alamos Scientific Laboratory is a national laboratory for medium energy physics; the heart of the facility is an 800-MeV proton linear accelerator used in the production of sub-atomic particles for physical and biomedical research and isotope production. (Page 1, last paragraph)
- † 6-GeV weak-focusing proton synchrotron. (Page 3, second paragraph)
- †† For example, the ISA Computer Control Workshop at Purdue University on June 11-14, 1973, contained a discussion of CAMAC standardization in computer control interfaces and associated hardware. (Page 7, last sentence)

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Figure Captions

- Figure 1. Basic Minicomputer System Configuration - caption on figure.
- Table I. Summary of Minicomputer Applications and Characteristics at LAMPF - caption on table.
- Figure 2. 750-KeV and 5-MeV Proton Beam Diagnostics System
- Figure 3. 805-MHz Accelerating Structure and Cavity Tuning Equipment
- Figure 4. Magnet Field Mapping Computer System and Mechanical Assembly
- Figure 5. Ion Source and Low Energy Transport Control Console
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- Figure 8. Biomedical Control Console

BASIC MINICOMPUTER SYSTEM CONFIGURATION

FIGURE 1

TABLE I

SUMMARY OF MINICOMPUTER APPLICATIONS AND CHARACTERISTICS AT LAMPF

APPLICATIONS	COMPUTER	CORE	CPU HARDWARE	PERIPHERALS
PROTON BEAM DIAGNOSTICS AT 750 MeV AND 5 MeV	NOVA	8 K	RTC, POWER FAILSAFE, DMA, INTERRUPTS	TTY, STORAGE DISPLAY, SHAFT ENCODERS, SPECIAL I/O
INTERFACE HARDWARE EVALUATION	SUPER NOVA	8 K	RTC, MULT/DIV, DMA,	TTY, STORAGE DISPLAY, PAPER TAPE, SPECIAL I/O, CAMAC
ACCELERATOR TUNING	NOVA	8 K	DMA, INTERRUPTS	TTY, STORAGE DISPLAY, SPECIAL I/O, CAMAC
MAGNET FIELD MAPPING	SUPER NOVA	12 K	RTC, MULT/DIV, DMA, INTERRUPTS	TTY, MAG TAPE, PAPER TAPE, INTEGRATING DVM, SPECIAL I/O
ION SOURCE CONTROL AND DIAGNOSTICS	NOVA	8 K	RTC, MULT/DIV, DMA, INTERRUPTS	TTY, STORAGE DISPLAY, PAPER TAPE, SPECIAL I/O
EXPERIMENTAL DATA ACQUISITION	PDP-11/20,45	16 K	RTC, MULT/DIV, DMA, INTERRUPTS	DECWRITER, CRT, MAG TAPE, DISK, CAMAC, PRINTER/PLOTTER
HARDWARE MAINTENANCE	PDP-11/05	4 K	DMA, INTERRUPTS	TTY, CAMAC
BIOMEDICAL FACILITY OPERATION	PDP-11/45	40 K	RTC, MULT/DIV, DMA, INTERRUPTS, MOS MEM.	DECWRITER, CRT, MAG TAPE, DISK, CAMAC
HIGH ENERGY BEAM DIAGNOSTICS	PDP-11/10	8 K	MULT/DIV, RTC, DMA, INTERRUPTS	TTY, CAMAC

Figure 2. 750-KeV and 5-MeV Proton Beam Diagnostics System

Figure 3. 805-MHz Accelerating Structure and Cavity Tuning Equipment

Figure 4. Magnet Field Mapping Computer System and Mechanical Assembly

Figure 5. Ion Source and Low Energy Transport Control Console

Figure 6. Laboratory Set-up of an Experimental Data Acquisition System

Figure 7. Biomedical Computer and Interface Hardware

Figure 8. Biomedical Control Console