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MINICOMPUTER APPLICATIONS AT LAMPF* **

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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.

Early in 1965, engineers and physicists at several laboratories installed minicomputers to handle a small portion of the beam transport control problem for accelerators. Since that time, the use of minicomputers for special instrumentation, data acquisition, and supervisory control has mushroomed throughout the accelerator world.

Being no exception to this trend, engineers and physicists at LAMPF have made a practice of applying minicomputer systems to assist in solving numerous instrumentation and control problems.

The paper describes current 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. Also, applications of PDP-11/05, /10, /20, and /45 computers to nuclear instrumentation testing, development, and data handling will be presented.

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 the LAMPF accelerator related to the production and acceleration of the proton beam. In addition, applications involving the acquisition of experimental area data are discussed. The acquisition and reduction of experimental data in other laboratories 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.

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. As particle accelerators have grown in size, complexity, and sophisitication, 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 and equipment control and off-line instrumentation for diagnostics, development, and maintenance tasks. This has been the case with the LAMPF accelerator.

Early in the design stages of LAMPF, a large central-computer control system was proposed for control of the facility. This ambitious project led to the application of a small computer control system on an electron prototype of the final accelerator. (2-4) This system was based on a Systems Engineering Laboratory 810A computer to support 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. (5) 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.

Presently, expansion of the aforementioned central-computer system at LAMPF is being accomplished through the use of minicomputers operating as satellites to the central control computer. (6)

* The Clinton P. Anderson Meson Physics Facility (referred to as LAMPF) 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.

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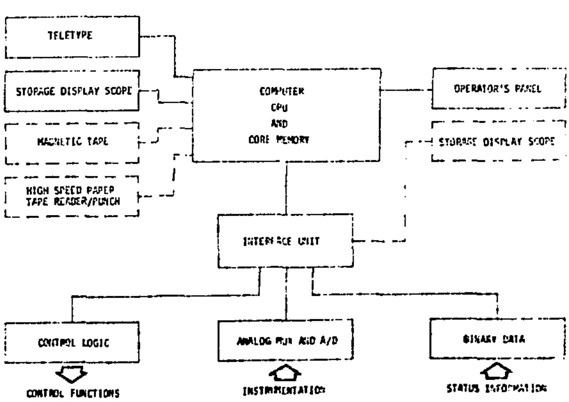
MINICOMPUTER APPLICATIONS AT LAMPF

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 configurations of their computer systems. This 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 was based as much on availability and cost as any other criteria. Then, as experience was gained in their application, the desire for compatibility continued the same computer selection until the need for several systems with different criteria dictated a change in computers. 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. (7) Most of the required control functions are commercially available in CAMAC modules which greatly simplifies the implementation of small data and control systems. The CAMAC standard is becoming an accepted means of computer interfacing throughout the accelerator world and also in some other disciplines.

The programming approach to the first systems was to write a minimum operating program 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 subroutines. These techniques proved to be fairly successful in the various applications described below.



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 KeV AND 5 MeV	NOVA	8 K	RTC, POWER FAILSAFE, DMA, INTERRUPTS	TTY, STORAGE DISPLAY, SHAFT ENCODERS, SPECIAL I/O
INTERFACE HARDWARE EVALUATION	SUPER NOVA	6 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	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
HARDWARE MAINTENANCE	PDP-11/05	4 K	DMA, INTERRUPTS	TTY, CAMAC
BIOMEDICAL FACILITY OPERATION	PDP-11/45	24 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

PROTON BEAM DIAGNOSTICS AT 750 KeV AND 5 MeV

One of the earliest uses of a minicomputer at LAMPF was on a data acquisition and control system to perform low-energy beam diagnostics. (8) This system, built 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 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 I/O functions. Special interfaces were designed for a storage display scope, shaft encoders, and the control and data hardware. The software consists of the "operating system," hardware test routines, a debug package, a bootstrap loader, and the beam diagnostics routines. The operating system is a group of stand-alone subroutines that can be called by other programs. The operator interaction with a running program is provided by switches which are serviced by interrupt routines.

750-KeV AND 5-MeV DIAGNOSTICS SYSTEM

FIGURE 2

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 another system to be described later. 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 was used to display the results of the measurements and 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

A second minicomputer system was developed to aid in evaluating interfacing techniques for experimental hardware. 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. Originally, this system serviced an experimental physics set up; but as it became obvious that some standardization in interfacing experimental hardware to computers was needed, the system was adapted temporarily to evaluate interface hardware. A fairly extensive software operating system was written to handle the high rates expected from some of the tests. Hardware test routines, debug programs, the bootstrap loader, 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 through various interfaces and display it on the storage scope or output it onto the magnetic tape. The results of these tests were to provide a measure of the different interfacing techniques. It was found, as a result of these tests, that the standard CAMAC interface provided as good a data gathering capability as an interface specifically designed for this application.

A MINICOMPUTER FOR ACCELERATOR TUNING

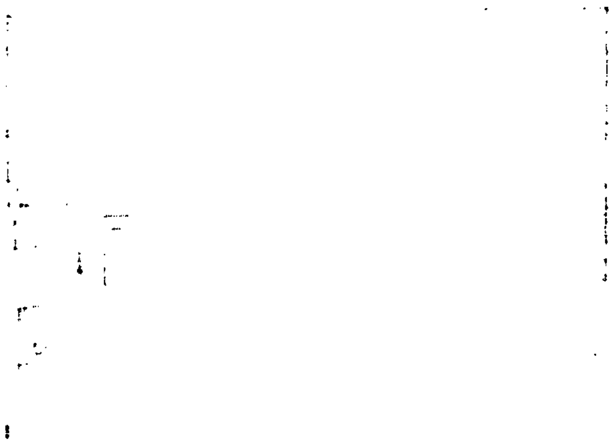
Another minicomputer system was developed to aid in tuning the 805-MHz accelerating cavities during their installation at LAMPF. This system also used a Data General Nova computer to control and reduce data from the hardware used in the tuning procedure. The equipment associated with this application 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 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 kept to a minimum. Nevertheless, the system provided the needed instrumentation and control functions and was instrumental in tuning the 4962 resonant cavities that make up 2400 feet of the accelerator.

ACCELERATOR TUNING

FIGURE 3

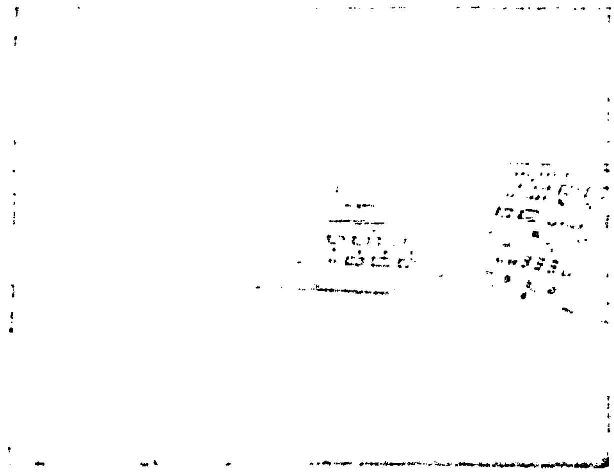
A MINICOMPUTER APPLIED TO MAGNET FIELD MAPPING

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 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. 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. Simultaneously, the computer gathers data and places it on magnetic tape for later reduction on a larger computer. The software has all been done in assembly language. The interface hardware was partially special units and partially an adaption of units developed in providing computer control of 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.



MAGNET FIELD MAPPER

FIGURE 4



ION SOURCE CONTROL SYSTEM

FIGURE 5

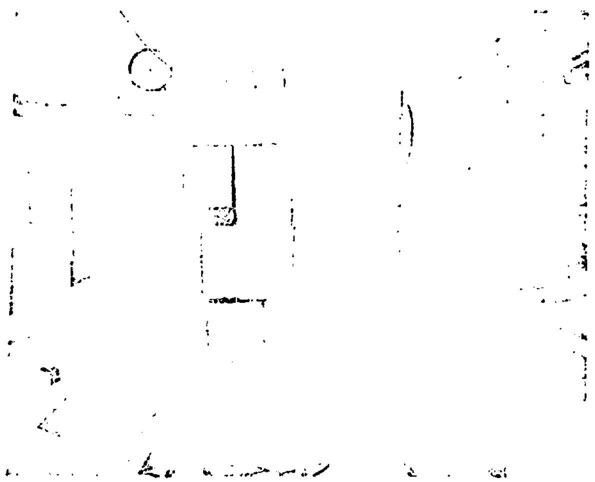
ION SOURCE CONTROL AND LOW ENERGY DIAGNOSTICS

The source of protons for acceleration at LAMPF is located at the high voltage terminal of a 750-kV dc power supply. Protons are accelerated to ground potential where they are transported 50 feet through a magnet and diagnostic system to the accelerator. The high voltage interface to the ion source, and its associated equipment, is crossed by a digital light-link system. The equipment at high voltage is controlled through a data acquisition and control terminal, [9] via the light-links, from an operators console in a nearby control room. Console servicing and ion source control are accomplished through a minicomputer system based on a Nova computer as shown in Figure 5. This system was built as a satellite to the central control computer for the accelerator and provides instrumentation and control of the ion source to the central system. [6] In addition to the ion source control, the 750-MeV and 5-MeV beam diagnostics previously described have been incorporated into this system.

Under programmed or operator control, the computer can obtain data from 64 channels of instrumentation and adjust the value of 25 different variables associated with the ion source operation. The computer peripheral I/O is through a teletype, paper-tape, storage display scope, and the meters, knobs, and other indicators on the control panels in addition to a link to the central computer. The software is all done in assembly language and loaded via the paper-tape. Local operator control is through program-serviced console switches or the teletype. The operators receive displays on the storage scope in addition to the meters and indicators driven by the computer. The 8192 words of core storage contain the system programs as well as the control and console servicing routines. This system has been in service for over a year and is presently being expanded to handle the operation of a second ion source for the accelerator.

EXPERIMENTAL DATA ACQUISITION AND BEAM LINE CONTROL

Results of an intensive effort to define requirements for experimental area data acquisition at LAMPF indicated that a minicomputer would be well suited to the task. [10] The system has evolved around DEC's PDP-11 family of computers. The computers, either 11/20's or 11/45's, were obtained with 16,384 words of core and are interfaced to magnetic disks, magnetic tapes, DECwriters, Tektronix 4010 storage scopes with keyboards, and through a Microprogrammed Branch Driver (MBD) to CAMAC packaged instrumentation and control equipment. A laboratory set-up of one of these systems is shown in Figure 6. Since there are a number of of these systems, they share a DECtape and paper-tape units. The MBD was designed as a special interface between CAMAC and the computer to increase the data transmission rate [11] (two MBD's are shown on the workbench to the right in Figure 6). The device is a stored program controller used to move data along the CAMAC data highway and provides eight channels of multiplexed DMA into the computers. The CAMAC units (the middle chassis in the right-hand rack) house the signal multiplexers, A/D converters, binary registers, and some nuclear instrumentation. The magnetic tape is the principal output device used by the experimenter. The storage scope is used for displaying pre-processed or stored data while the experiment is on-line. The disk contains the operating system, display and data reduction programs, and acts as an intermediate storage device for the system. The disk operating system (DOS) supplied by the manufacturer is the basic software unit. It has been expanded to facilitate operation with the MBD. Various amounts of pre-processing of data can be done either by the stored program in the MBD or by the computer. Many display and data programs have been written in assembly language and made into FORTRAN callable subroutines. The users of the systems do the bulk of their programming in FORTRAN.



EXPERIMENTAL DATA ACQUISITION SYSTEM

FIGURE 6

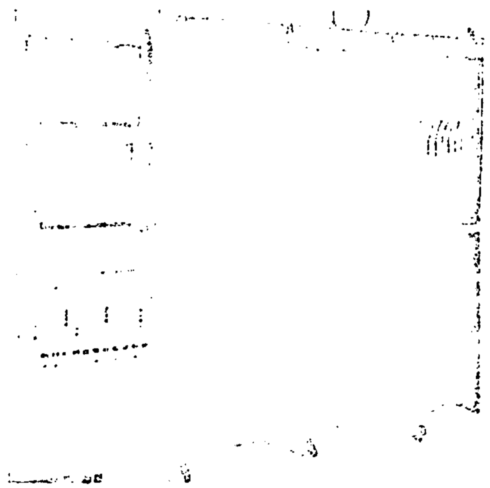
The purpose of these systems is to provide high-speed data transmission and storage for an experiment being performed using the particle beam. In addition to that purpose, the computer will have control of the beam line equipment for set-up and on-line adjustment of experimental parameters. The development of these systems is still underway, but it is hoped that the basic hardware and software will be flexible enough to service the many uses envisioned for them.

HARDWARE MAINTENANCE AND DEVELOPMENT WITH A MINI-COMPUTER

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 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.

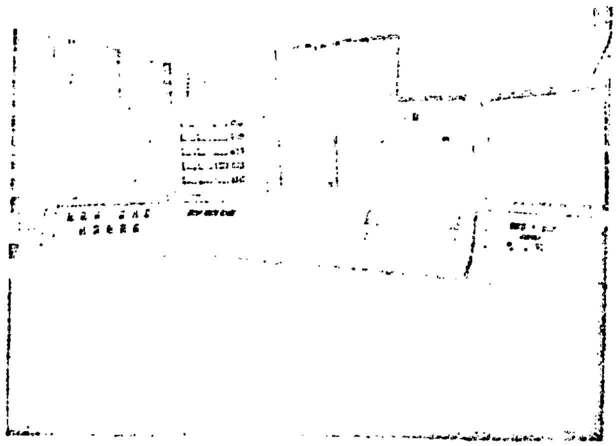
MINICOMPUTER OPERATION OF A BIOMEDICAL FACILITY

In addition to the basic physics research accomplished with the accelerated beam at LAMPF, a biomedical 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 two treatment rooms with all their associated instrumentation. The operation of the facility is to be accomplished with one of the experimental data acquisition systems. This application uses a PDP-11/45 computer interfaced to the instrumentation and control hardware through the MBD-CAMAC system as seen in Figure 7. (The left-hand rack contains two powered CAMAC crates plus other interface hardware.) Furthermore, the computer supports an extensive operators console for operation of the facility. Figure 8 shows one half the final console under development. Operator interaction will be mostly through the storage scope displays and program assignable function buttons and knobs. (12) The bulk of the hardware used in this facility was developed for other applications and adapted for use here. The programming requires a full-time systems programmer who uses the manufacturers operating system software and provides the basic programs for operating the facility. In addition to hardware operation, the computer system is used for treatment planning and patient record keeping.



BIOMEDICAL COMPUTER AND INTERFACE

FIGURE 7



BIOMEDICAL CONTROL CONSOLE

FIGURE 8

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. (9) 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/second) 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.

CONCLUSIONS

The application of minicomputers to the various areas described in this paper has provided considerable experience to the engineers 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 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 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. This has provided an added degree of flexibility to match the nature of the work in a research laboratory. Having developed several special I/O interfaces, their utility in an application where the equipment configuration is fixed can be appreciated. However, in a more flexible application, the use of a standard interfacing technique such as CAMAC saves design time and speeds implementation of the computer system; it allows 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 packages. Still, a good deal of design and checkout time is required to make the individual logic packages function properly as an operating system.

In the accelerator community, adapting the process instrumentation and control equipment to the computer has been the last 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, instrument and control equipment designers are cooperating and providing both on/off status and 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 the minicomputer applications throughout the accelerator community will continue to proliferate at the various laboratories.

REFERENCES

1. Proceedings for the Skytop Conference on Computer Systems in Experimental Nuclear Physics, USAEC Division of Technical Information, CONF-690301, October 1969.

2. T. M. Putnam, et.al., "The Application of a Digital Computer to the Control and Monitoring of a Proton Linear Accelerator," 1965 Accelerator Conference, IEEE Transactions on Nuclear Science, Vol. NS-12, No. 3, June 1965.

3. H. S. Butler, et.al., "Computer Control of the LAMPF Accelerator," Proceedings of the 1966 Linear Accelerator Conference, Los Alamos Scientific Laboratory Report LA-3609, October 1966.

4. R. A. Gore, "LAMPF Control Philosophy," Proceedings of the 1968 Proton Linear Accelerator Conference, Brookhaven National Laboratory Report BNL-50120, May 1968.

5. M. D. J. MacRoberts, et.al., Programs for Computer Control of EPA," Ibid.

6. D. R. Machen and J. M. Potter, "The Satellite Minicomputer - A Practical Solution to Accelerator Control," 1973 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, Vol. NS-20, No. 3, June 1973.

7. "CAMAC - A Modular Instrumentation System for Data Handling," USAEC Publication TID-2585, July 1972.

8. D. R. Machen, "A Computer-Based, Data-Acquisition, and Control System for LAMPF Beam Diagnostics," Proceedings of the 1970 Proton Linear Accelerator Conference, National Accelerator Laboratory, October 1970.

9. D. R. Machen, R. A. Gore, and D. W. Weber, "A Compact Data Acquisition and Control Terminal for Particle Accelerators," 1969 Particle Accelerator Conference, IEEE Transactions on Nulcear Science, Vol. NS-16, No. 3, June 1969.

10. "LAMPF Data-Acquisition System," Los Alamos Scientific Laboratory Report LA-4504-MS, August 1970.

11. L. R. Biswell and R. E. Rajala, "A Microprogrammed Branch Driver (MBD) for a PDP-11 Computer," Los Alamos Scientific Laboratory Report LA-4916-MS, April 1972.

12. B. L. Hartway, "A Compact Programmable Control Panel for Computer Control Systems," 1973 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, Vol. NS-20, No. 3, June 1973.