© 1973 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

THE CENTRAL CONTROL ROOM MAN-MACHINE INTERFACE AT THE

CLINTON P. ANDERSON MESON PHYSICS FACILITY (LAMPF)*

by

B. L. Hartway, J. Bergstein, C. M. Plopper

University of California Los Alamos Scientific Laboratory Los Alamos, New Mexico

Summary

The control system for the Clinton P. Anderson Meson Physics Facility (LAMPF) is organized around an on-line digital computer. Accelerator operations are conducted from the Central Control Room (CCR) where two identical but independent operator consoles provide the man-machine interface. This paper traces the evolution of the man-machine interface from the initial concepts of a computer control system. Special emphasis is given to the human factors which influenced the development. The way in which an operator interacts with the system is illustrated by a description of an accelerator operating sequence.

Introduction

The LAMPF is being built to provide a unique tool for research in medium-energy nuclear physics and for associated practical applications. The heart of the facility is a half-mile long linear accelerator capable of producing 1 mA (average) of 800-MeV protons.

The control system for the LAMPF is organized around an on-line digital computer.¹ This control system was designed to provide the operations staff with adequate tools for understanding the behavior of the accelerator, for optimizing its performance, and for maintaining it in productive operation. In the system design all data and controls essential to the operation of the accelerator were multiplexed through the computer to CCR where the operator could interact with the system based on his interpretation of the data displayed on various computer-driven devices. Because all facets of this operation were determined by computer programs written in FORTRAN, the flexibility inherent in the system was virtually unlimited.

Prototype Console

In the first attempt to provide the control system interface for the above requirements, an operator's console was built and installed as an integral part of the computer control system for the LAMPF Electron Prototype Accelerator. This prototype console and supporting software verified that it was feasible to operate an accelerator through a computer. One of the key features of the console was a graphical display scope with an interactive light pen for control.² This single scope replaced the myriad of hardware control panels so common in accelerator control rooms. An alphanumeric display scope and keyboard provided the operator with a second means for registering his judgment by altering a sequence of operations or by redefining set points, parameters, or constraints. Some of the other hardware developed for the console included function buttons, thumbwheel-switch channel selectors, and a computer-controlled pulse viewing system.

The most difficult design problem was the man-machine interface at the operator's console. There are over 2500 analog signals and 2500 status indications available to the computer which can gather data at a rate in excess of 24,000 words/second (a word being one analog measurement or 12 status indications). A total of 1500 knobs and 2000 relay closures can be controlled through the computer. Since the primary mode of operation is based on open-loop, set-point control with the operator acting in a supervisory capacity, it was essential that the data be organized and displayed for the operator in a format which quickly conveyed the status of the whole accelerator or any subsystems under study. Similarly, there had to be a simple but flexible scheme for the operator to manipulate the various controls.

The experience gained from the prototype console was incorporated in the design for the LAMPF operator's console. A mockup of the console was built and evaluated from many points of view. Several human-factor studies were performed to determine the optimum shape of the console and the location for various controls. The goal was to develop a console that could be operated by one person but which could accommodate two persons comfortably. Also, due to the anticipated size and complexity of the LAMPF control system, it was decided to eventually incorporate multiple identical operators' consoles for reasons of (1) enhanced reliability, (2) operator training, (3) simultaneous access to the accelerator by more than one operator, and (4) extended capabilities for operating the experimental areas.

First LAMPF Operator Console

The LAMPF operator's console went through one more stage of evolution. The first of three custom cabinets ordered for CCR was fitted with the latest versions of devices thought to be essential to the console. These devices included the graphics display scope, the alphanumeric keyboard and scope, six raise/lower knobs on two panels, 60 function buttons on two panels, a trackball, a storage display scope, an oscilloscope, a communications station, and a closed-circuit TV (CCTV) monitor.³ The console was successfully used in the 211-MeV beam test at LAMPF. During most periods of operation, the console was occupied by an operator who used the controls in cooperation with the accelerator physicist conducting the investigation.

The success of the console was due, in no small part, to the software which supported its operation. The systems programs to drive each device were written by professional programmers in assembly language. Then a FORTRAN interface in the form of a subroutine calling sequence was created for each device, allowing the development of an extensive library of subroutines and control software. This made the systems programming transparent to the console user and allowed physicists to develop most of the accelerator operating programs.

As the tempo of accelerator operations increased, it was clear that the second console was needed. This had been anticipated by the order for three console cabinets. However, the instrumentation of the second console was being postponed as long as possible to take fullest advantage of the experience being accumulated.

Final LAMPF Operator Console

In the subsequent design review it became evident that the main weakness of the first console was its inability to adapt hardware panels to different operators performing different tasks. The efficiency of an operator depended on his having a display scope coordinated with an appropriate set of controls and indicators for each specific task, and on his being able to switch rapidly from one task to the next. Moreover, it was important to have a way to indicate continuously the status of certain critical systems.

* Work performed under auspices of USAEC.

These problems were resolved by the development of a small control module called the card programmable function button panel.⁴ It consisted of a panel of 30 function buttons with indicators which could be assigned in over 1000 ways by the insertion of any one of 1000 program cards which the computer could recognize. Each program card provided its own labeling for the function buttons and indicators. The ability for variably-assigned function buttons and indicators did much to enhance the flexibility of the console.

An important adjunct to the card panel was the analog slew module. It consisted of three raise/lower knobs with adjacent alphanumeric readouts. Special buttons were installed beside each knob to provide the computer with instructions for different knob sensitivities and resolution. The readouts could be addressed by the computer to provide the operator with suitable knob identifications or messages whose maximum length was 32 characters. The slew module was built in a modular construction, as was the card panel described above, for ease of maintenance and for ability to be relocated easily in the event of console rearrangement.

With the deficiencies of the first LAMPF console thus corrected by the card panel and slew module, construction of the second console was begun. Three of the card panels and two of the slew modules were incorporated into its construction. Other instrumentation improvements incorporated at this time included the following: (1) The replacement of the black and white alphanumeric scope with an equivalent color scope to provide for increased information and display flexibility, (2) The addition of a second storage display scope to provide the operator with a greater capacity for diagnostics displays, (3) The addition of a second communications set to accommodate independent communications functions when two people occupied the console, and (4) The replacement of the single 12-inch CCTV monitor with dual 9-inch monitors to provide for additional information display capacity. During the construction and operational checkout of the second console, a continuing effort was made to reevaluate the human-factors environment of the man-machine interface. The resulting improvements were as follows: (1) The elimination of bothersome light glare on various console displays by special treatment of the room's windows and light fixtures; (2) The provision for further eye relief for the operator by the painting of all console panels with a dark neutral-color paint; (3) The improvement of the console's deskwork-ability by the widening of its writing surface and the provision of book spaces in its upper panels; (4) The elimination of potential hardware clutter of the console control panels by the front panel removal of all non-essential indicators, switches, and adjustments; and (5) The enhancement of the operator's ability to adjust to the computer's response for various commands by the addition of audible clicks and blinking lights on appropriate control panels.

The second console was thus completed. All accelerator operations were then transfered from the first to the second console while the first console was retrofitted to an identical configuration (see Figure 1). All of the design objectives of the LAMPF opera-

All of the design objectives of the LAMPF operator's console had been fulfilled as a result of the console's capability to provide diagnostic and control functions equal to the multiplexing capabilities of the computer control system. The completion of two identical consoles allowed the realization of the earlier goals for multiple console operations and was instrumental in bringing the LAMPF into final operational status.⁵

Console Use for Accelerator Operation

The "operator" at the control console could actually by any one of the following: (1) an accelerator "beam-time" operator, (2) a programmer doing operations or development work, (3) a physicist doing experimental or developmental work, (4) a system analyst, engineer, or maintenance technician doing surveys, calibration procedures, or systems development. The flexibility of the consoles' control hardware allows all these various operations with equal facility since the operator actually predefines the console control hardware to a configuration appropriate to his task through the use of the card panels. Moreover, by virtue of the immense manpower investment in the programming of the LAMPF computer, the operator has access through the computer to the equivalent of 20 man years of experience, approximately 10 in systems programming and 10 in control applfcations programming. The only outward evidence of the programming ivestment is the relative ease with which the operators perform their various tasks at the console.

A typical operational routine at the console would result in the following sequence. The operator inserts a program card in a card panel which provides him with the desired set of routines for program callup and control and status indication for critical systems. He then uses the graphic and/or alphanumeric scope(s) for program display and interaction. He will interact with the graphics scope by using the light pen and interact with the alphanumeric scope by using the keyboard. He uses the keyboard to specify program options, modify displayed instructions, and specify the resultant format of graphical diagnostic data to be plotted on storage scopes. He further specifies which storage scopes are to be used for each program and whether or not they will be linked to the hard-copy and CCTV scan-conversion terminals. He will use program cards in the remaining card panels for the assignment of special controls such as function buttons and knobs. He will use the readouts beside the knobs to display the knobs' functions. Finally, he will use the communications system in conjunction with the CCTV and video systems to communicate with colleagues at other locations at the LAMPF and transmit to them or receive from them various information displays.

Typical Applications Programs

The use of the console and the supporting software programming can best be illustrated by an actual accelerator operating sequence. The following examples are offered for purposes of illustration only and by necessity make reference to several terms unique to the LAMPF.

Accelerator Turn-On

The operator inserts an Accelerator Status Card into the large card panel in front of him and pushes the 805 TURNON button (see Figure 2). The 805 Sector Status Display for the accelerator's first sector appears on the round graphic scope. The operator prepares the 805 Section of the accelerator for Run Permissive condition by light pen control on the display. As he progresses, he will sequentially call up the displays for each of the accelerator sectors, A through H, by light pen hits on those characters in the display's title. The display itself consists of a matrix of control systems versus modules in the sector. Each matrix point symbol (+, -, or 0) represents the status of the control system in each module. The control systems represented in the matrix are water, vacuum, quad magnets, valves, RF, etc. A+ indicates ON, an R indicates ready for command to ON, and a 0 indicates something not ready. A light pen hit on an R will cause the computer to automatically sequence the system to a + condition. A light pen hit on a + or 0 gives an alphanumeric scope line display of all the elements in that system in that module. The operator uses the keyboard with the line display to interact with the system as desired.

Optimization of 800-MeV Beam

The operator pushes the 805 SETUP button and gets an appropriate display on the alphanumeric scope (see

Figure 3). By using the keyboard he will, in this example, select the TWEEK option. Through further options, he will select a group of eight accelerator modules. A display will then present eight sets of X and Y steering magnet currents. Placing his alphanumeric scope cursor (by using keyboard or trackball) under any one of the current values will assign control of that magnet to a knob on the slew module. The knob will be identified as TWEEK by the adjacent readout. He pushes the 805 DISPLAY button and another program is displayed on the alphanumeric scope providing him with display options. He selects a three-graph, real-time storage scope display of (1) beam current, (2) instantaneous beam spill, and (3) time-averaged beam spill - each being plotted versus position along the accelerator. Another button produces a storage scope display of magnified real-time beam current just ahead of the target. By using this control configuration, he can now judge the effects of magnet currents on beam optimization. Due to the continuous storage feature of the displays, the operator is easily able to identify maximum and minimum conditions. Using the keyboard, he can then identify selected optimum values of current for STORE, which means that the new values will be stored by the computer for future use.

Conclusions

The goal of every accelerator center is the optimization of accelerator performance against some set of criteria. With the advent of computer control, this tedious and exacting reduction of diagnostic data can now be rapidly accomplished and the results plotted in graphical form ready for immediate human evaluation. It is therefore possible that the ultimate optimization and operating efficiency of the accelerator will be determined by the effectiveness of the man-machine interface. For this reason, we feel that human-factors engineering and information display concepts will become increasingly important in the near future. We have accordingly invested a full-time effort in this endeavor at the LAMPF.

Acknowledgments

The successful design of the LAMPF operators' control consoles would not have been possible without the dedicated work and generous cooperation of the entire staff. The authors are especially grateful to both Dr. D. A. Swenson for his tireless dedication to the perfection of the consoles and Dr. H. S. Butler for his generous assistance in the preparation of this paper.

References

- Butler, H. S., "A Computer-Based Accelerator Control System," presented at the ISA-70 Conference, October 1970.
- Butler, H. S., "Computer Control of the Los Alamos Linear Accelerator," 1967 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, NS-14, No. 3, June 1967.
- H. S. Butler, B. L. Hartway, D. R. Machen, and T. M. Putnam, "An Accelerator Operator's Console for the LAMPF Accelerator," 1971 Particle Accelerator Conference, IEEE Transactions on Nuclear Science, NS-18, No. 3, 1971.
- Hartway, B. L., "A Compact Programmable Control Panel for Computer Control Systems," presented at the 1973 Particle Accelerator Conference, March 1973.
- Butler, H. S., "Performance of LAMPF Computer Control System," presented at the III All-Union National Conference on Particle Accelerators, USSR, October, 1972. Proceedings to be published, reprints available from author.



Figure 1

One of the two identical LAMPF CCR operators' consoles. (The racks in the rear are for CCR access to various distributed systems.)



Figure 2

Accelerator turn-on using the 805 Sector Status Display on graphics scope, selected line display on alphanumeric scope, and Accelerator Status Card in card panel.



Figure 3

Optimization of 800-MeV beam using 805 SETUP on alphanumeric scope with TWEEK program, an 805 Display on the storage scope, and a slew module and card panels for control and readout.