LAMPF CONTROL PHILOSOPHY*

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Introduction

The proposed control system for the Los Alamos Meson Physics Facility (LAMPF) has been described at every accelerator conference since 1965. The earliest of these articles[1] presented a fairly complete list of the possible applications for a computer-based accelerator control system. Later papers[2,3] gave descriptions of the proposed LAMPF control system based on the computer capabilities. A paper to be presented at a controls conference next month[4] carries a more detailed and complete description of the proposed LAMPF system, along with some preliminary results from a computer control system for an electron prototype accelerator. This paper is an attempt to document the approach, as seen at this time, that is to be taken in the actual implementation of the control system.

There has been at Los Alamos for several years an energetic experimental program associated with the Meson Physics Facility. The purpose of this program has been to verify certain theoretical aspects of the accelerator and to mockup prototype equipment for various accelerator subsystems. This program has resulted in the fabrication and operation of an electron prototype of the LAMPF accelerator. This accelerator, among other functions, has provided a test vehicle for the computer control system of the LAMPF. The electron prototype accelerator (EPA) has provided the opportunity to develop and test both the programs and equipment necessary to operate the LAMPF accelerator. Although the final versions of both hardware and software are still in the developmental stage, the experiment has established the feasibility and capability of performing essentially all of the accelerator control functions.

Establishing the capability of performing certain tasks is only part of the overall control problem. Many related areas of concern affect the final design of a control system, e.g., economics, operators, operating modes, and system requirements. Recognizing this, a control philosophy committee was created to provide guidance in developing the proper control system for LAMPF. As a result of this committee's efforts, certain guidelines and requirements have been established for the control system. These requirements, plus those generated from other sources, have been put together in the system descriptions that are presented here.

This paper will rely on the existence of the previous articles describing the operation of the control system; in this way, repetition will be avoided. The basic areas of control are defined first, followed by brief descriptions of the various operating systems and a discussion of the basic approach to the computer control of the accelerator. Next, the results of computer control of the EPA are presented and some concluding remarks are made about the lessons learned from the effort.

Control Areas

The Los Alamos Meson Physics Facility is geographically distributed over a half-mile of real estate but for control purposes, the facility can be divided into two categories — local control and central control. The local controls are provided for the installation, checkout, and maintenance of equipment in the vicinity of the main beam channel. These controls are generally grouped on a module basis along the machine, where a module is defined by an rf power source, that portion of the beam accelerating structure which it powers, and associated electrical equipment. The local controls will provide control of all of the equipment in the module. They will contain the necessary protective and safety interlocks and instrumentation to properly operate the associated equipment. Module-to-module communication between local controls along the length of the accelerator will be kept to the minimum necessary for safe operation of the equipment.

The central control system will be based on a digital computer performing on-line, real-time control and data acquisition. To tie the local controls to the central control, present planning calls for each module to have separate computer control interface equipment located in the local control racks. It may develop that more than one module will be serviced by a given interface unit but for now the one-to-one relationship will be assumed to exist. The interface equipment is a multiplexing unit which channels the data in digital form from the module to the central control room (CCR) and distributes control commands from CCR to the module equipment. Since CCR commands to the module equipment operate through the module local controls, they are restricted by the same set of interlocks effective in the local mode of control. The operation of the module equipment from CCR or from the local controls is selected by a noninterrupting local-computer mode switch located on the local controls. The data originating at the module for display at CCR is unaffected by the local-computer mode selector switch. These data, which are always available for computer selection, allow the computer to be fully aware of the operating status of the accelerator, whether or not it has full control.

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Control of the accelerator facility as an entire unit will be accomplished from the CCR. During normal operation of the accelerator, the operator will have available displays of all the necessary data. The operator will be able to command the required hardware changes to produce beams of various energies, pulse widths, and intensities. In the event of certain types of failures, the operator will have at his command various emergency procedures to maintain or recover full accelerator operation. In order to provide for CCR control of the accelerator in the different modes of operation, one must insure that all of the necessary data and controls are available and that the operation of each area is well understood by the operator. The means of establishing the data transmission between CCR and the accelerator modules are detailed in other papers.[3,4] In the event the CCR interface equipment at a given module or two should fail, it would be feasible to continue accelerator operation with operators at these modules. However, if the central control facility should fail, it would be difficult to continue operation.

System Control and Instrumentation

There are four major areas in this facility: the injector, the drift-tube linac, the side-coupled linac, and the experimental area. These areas have many of the same types of operating systems, e.g., vacuum, water, magnets, etc., and from a controls point of view they look quite similar. Therefore, allowing for the detailed differences in each area, the instrumentation and control of these systems can be uniform throughout the length of the accelerator and it is entirely proper to discuss the requirements on a system basis. In order to implement the various systems to be compatible with the operational requirements, specifications for the control and instrumentation have been determined. These specifications have set the instrumentation and control required at CCR for each system. These requirements for the various systems are listed below:

Vacuum System

1. Control and position indication of all beam-line vacuum valves.
2. On/Off status indication of all vacuum ion pumps.
3. Ion pump current or a preset limit indication.
4. Selected vacuum ion gauge readings.

Water System

1. On/Off control and flow indication for all accelerator cooling water pumps.
2. Control of the set points of the tank temperature controllers.
3. On/Off control of tank water heaters.
4. Tank temperature measurements.
5. High temperature indications of selected water-cooled devices.
6. Flow indications for critical water-cooled devices.

Magnet Systems

1. On/Off control and current set point control for the magnet power supply.
2. Magnet current measurements.
3. High temperature indication on the magnets where required.

Beam Monitoring System

1. The beam current and position monitor output pulses will be available at CCR for oscilloscope display.
2. These pulse amplitudes will be measured, digitized, and read into the computer through the analog data system.

RF Systems

1. On/Off control of filament and cooling.
2. On/Off control of high voltage.
3. Status indication of selected internal circuits.
4. Control of the set points of the fast phase and amplitude control loops.
5. Control of the timing of the rf pulse.
6. Selected rf pulse waveforms will be available at CCR for oscilloscope display and as digitized data for the computer.

The above systems requirements are those which are essentially uniform along the length of the accelerator.

There will be a need for special instrumentation in the injector area for the operation of the ion source and related equipment. It is sufficient to state here that the computer will have complete control of the injector during normal operation. In the experimental area the implementation of the above systems refers only to the main beam line and the permanently installed secondary beam line equipment and does not apply to equipment related to a particular experiment.

In addition to the above systems, there are a number of distributed operational systems that the computer will monitor or control. These are listed below:

1. The computer will control the timing system for the injector and rf units.

2. The computer will monitor the accelerator fast shutdown system and collect fault data immediately after a shutdown occurs.

3. The computer will monitor the radiation and personnel safety systems and the facility equipment.

The above lists represent a substantial amount of planning for the proper instrumentation and control of the various systems. In all cases a certain amount of flexibility is being designed into the systems to accommodate necessary additions and modifications. These lists will form the basis for the final design of the control system.

Computer Operation

The basic approach to the computer control of LAMPF is one of programmed operation. This requires, in addition to the instrumentation and control outlined above, that programmed into the computer is the complete knowledge of the accelerator operation. To generate the programs prior to initial operation of the accelerator requires definition of the operating procedures and characteristics of the operating systems throughout the accelerator. Each of these systems must be considered with respect to the different modes of operation: (1) initial turn-on, (2) normal operation, (3) non-normal operation, and (4) diagnostic and maintenance operation of the accelerator equipment. The instrumentation requirements for each system must be reviewed to insure compatibility with these procedures. Such system descriptions are being acquired for LAMPF through the operation of the various experimental prototypes of the equipment for the final machine and particularly through the operation of EPA. Many of these programs will be useful even in the initial phases of the accelerator operation. In addition to the computer programs developed to operate prototype equipment, there will be new programs developed for special LAMPF functions. In areas where special programs are not available for a given operation, the general control programs can be used. The effort to gain full program control of the accelerator as early as possible will retain a high priority.

Computer Control of EPA

The electron prototype accelerator was planned as a mockup of the LAMPF accelerator to develop and test the basic structures, the 805-MHz rf units, and the control system. The controls were to be designed to achieve full computer operation of EPA. Operation of EPA was initially achieved with the local controls and operation continued in this manner for several months. Since that time the development of operational programs has progressed to the point where it is now possible for the computer to turn on the accelerator, steer a low intensity beam through the first two current monitors, and then shut down the facility. An outline of the steps involved will be informative because it points up the interplay between operational procedures and the instrumentation necessary to implement the procedures.

The turn-on programs process several devices simultaneously. Preparing the preaccelerator (Model M) for rf involves checking the temperature controller, turning on certain water pumps and checking their flow, turning on the tank heater, and checking the tank vacuum. The turn-on sequence for the Model M Intermediate Power Amplifier (IPA) required turning on a water pump and the filament, checking the air and water flow and then, after a 10-minute delay to allow the filament to warm up, checking a trio of interlocks. Concurrently with these actions the rf pulse length from the master pulser is set to 500 μsec and pulsing is initiated. Upon completion of these three programs, the computer turns on the high voltage to the IPA and starts to run up the rf power. Since this causes heating of the Model M cavity, the computer must monitor the copper temperature and pause in the run-up if it gets too high. Also, the computer has to watch for faults in the protection circuitry caused by sparking. Upon detection of a spark, the fault circuit is reset and after 10 seconds pass without a fault, the run-up is continued.

Running in parallel with the programs above are other programs which prepare the target area for beam, set the beam-line magnets to their nominal polarities and currents, warm up the EPA cavities, prepare the 1.25 MW Klystron for high voltage, and condition the electron injector for high voltage. This last program is followed by another to run up the current to the electron gun filament. Completion of all these programs brings in the beam run-up program which is followed by the beam steering program. The computer begins the search for the beam by setting to zero the currents through two magnets which steer in the horizontal and vertical directions. Then the currents are adjusted to move the beam along an expanding square spiral until the beam current measured in the nearest current monitor reaches a threshold value. The program then goes into an optimization procedure which works alternately with the horizontal and vertical magnets to maximize the beam current through the current monitor. The optimization algorithm is especially tolerant of noisy signals, a variety of beam profiles, and magnet hysteresis. Upon completion of the steering operation, the facility can be shut down with the operator having the option to leave various major subsystems operational.

In addition to the operating programs outlined above, a sizable effort has been put into improving the data handling and displaying programs to make the operation more efficient. As a result of the operational experience gained on EPA, many early ideas had to be modified and new ones incorporated into the control system. This experiment is continuing and it is certain that much more will be learned in the future operation of EPA.

Conclusions

The experience on EPA has demonstrated the feasibility of computer control for the LAMPF accelerator. This experience has been helpful in establishing an approach to the implementation of computer control. From the beginning, it was planned to use computer control for the EPA and all of the local control hardware was designed to be compatible with the computer interface equipment. This advanced planning saved a great deal of time and effort in adapting commercial equipment to computer control. Furthermore, any necessary circuit modifications were done prior to initial installation; this avoided the necessity of modifying equipment after it had become operable. Hence, by realizing that computer control does not stop at the interface hardware — it affects almost every circuit in the accelerator — time and money can be saved in the proper design of the local control equipment.

The programming for computer control is as essential as the hardware design. The basic computer data handling and display programs for EPA were written very early in the design phase. The various operating programs were developed more slowly. The operating programs were acquired by interpreting manual operating procedures for the different systems into computer programs. Once the programmers were given complete system descriptions and operating requirements, they were able to produce efficient programs to operate the accelerator. This is a very heuristic approach to accelerator control and for systems with a large number of variables, e.g., the beam steering, it is possible that better control could be achieved through a more analytical approach to the problem.

It is a well established fact in computer installations that the demand for computer time will eventually saturate the capability. To some extent this is also true in computer-controlled installations. Once the accelerator is in operation under computer control, many of the routine tasks performed by operators can be done better by the computer and planning for this capability should be incorporated into the early stages of system design. Thought was given to this possibility in the design of the EPA control system. The initial number of control and instrumentation channels for EPA was considered more than adequate; thus, allowances were made for only 20% spare channels and, today, essentially all of the channels are in use. Another reason to design flexibility into the system is for use of the computer as a data acquisition system for experiments performed on the accelerator.

The work on EPA represents a substantial amount of progress in the field of computer control of linear accelerators but it also brings to light other areas of potential application of computer control of accelerator equipment. The main extension of the computer capability might be in the area of local closed-loop control where the dynamic response time of the system is in the range of the computer sampling rate. In this area, local controllers require individual electronic control and compensating circuits and direct digital control may provide savings on hardware and improve the overall reliability. Such control loops as for the tank temperature or large magnet currents may be in this category.

Even with the experience gained in EPA, it is not claimed here that all of the problems of computer control of linear accelerators have been solved, but it is felt that a significant step in the right direction has been taken.

Acknowledgments

A task having the magnitude of the LAMPF control system obviously requires the concerted efforts and cooperation of a large group of people. The basic control and instrumentation system designs are under the direction of Dr. T. M. Putnam; the local instrumentation and system operations are under the direction of: Drs. C. R. Emigh for the injector, D. A. Swenson for the drift-tube section, E. A. Knapp for the side-coupled cavity sector, D. R. F. Cochran for the target area, and D. C. Hagerman has the responsibility for the rf units. In addition, the efforts of Dr. H. S. Butler on the computer programs for the system must be recognized as invaluable to the success of this operation.

References

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DISCUSSION

(R. A. Gore)

BAYLY, AECL: Can you say approximately how many data-gathering channels and how many control channels are involved?

GORE, LASL: Yes, we recently went through that exercise for a typical 805 module. There are 45 of these in the machine. And listed as desirable or necessary, by the various peoples involved, were 47 analog data channels, each one requiring special consideration. I believe there were also 17 analog command channels. Each of these is a "turning of a pot" type thing, and other various on-off controls.

BAYLY, AECL: And does this saturate the 810?

GORE, LASL: We don't propose to use the 810A on LAMPF right now, so I don't know. It does not saturate the capability of the remote equipment. The 810A has only 8k of core memory and then it uses a disk for the basic program and storing of data and so "saturating the capability" is a relatively nebulous question.

ALLISON, LRL: Based on your experience with the EPA could you give a breakdown of the expected failure rates, comparing analog and digital equipment?

GORE, LASL: The computer seems very reliable. Starting with the control room, the disk seldom fails, but when it does, it is disastrous. The computer interface unit has had several failures over the six months. The remote equipment, which is digital in nature, takes the transmissions from the control room and distributes them to various elements. This equipment, being prototype equipment and being unusual packages, led us to a number of hardware problems and our current failure rate in that area would be unacceptable for LAMPF but it has improved in the last four months. We had a lot of trouble getting this equipment on the air in the beginning. We would have failures that would last a day or two and occur every three or four days. Recently, we have gotten most of the bugs out of this equipment and now we can operate almost any time we want with little effort. The analog instrumentation, as it is made, requires a different type of reliability. Not only does it have to work, it has to work properly, not in just an on-off state. The instrumentation we have made seems to be reliable but it is influenced by a lot of things: temperature in the racks, amplifiers used, this sort of thing. We hope we have a "handle" on this now and most of our analog measurements are now becoming very reliable.

LOEW, SLAC: What criteria are set for the selection of the computer for control of LAMPF, based on what you have learned sofar?

GORE, LASL: I would rather let Hal Butler tell you about that. We haven't gone out to bid on that computer yet nor have we set the complete specifications. The SEL 810 has a 16 bit word. It seems one of the criteria is a longer bit word. The 8k core memory seems low. We would like more core memory to handle more readily available programs. Getting programs from a disk is quite a time-consuming operation. We would like to get a faster disk. We now have one head per side. One head per track would increase the speed of operation.

BAYLY, AECL: This may be an indiscrete question, but do you have some idea of the relative cost of the computer as compared to the entire instrumentation system?

GORE, LASL: Yes, it is an indiscrete question. It appears that the instrumentation and interface will probably cost between half as much as the computer and as much as the computer, depending on the type of instrumentation we go to. The analog channels are expensive. Depending on the type channels, they cost 150 to 300 dollars per channel.

WATERTON, AECL: What signal levels do you use on your analog and digital cables and what are the signal-to-noise ratios?

GORE, LASL: The signals are generated at any level from a few millivolts to a few hundred volts but they are "conditioned" to 0 + 10 volt for an A to D converter. The transmission level has been set at 15 volts for pulses. Right now we are using a single polarity nonreturn to zero code with a 15 volts pulse on it. We are going to a bipolar pulse which carries its own timing with it and this also will use 15 volt pulses.

WATERTON, AECL: In buying equipment for 0 + 10 volt signals, what signal-to-noise ratio do you ask for, or alternatively what accuracy to you expect?

GORE, LASL: We are doing 10 bit conversion which implies one part in one thousand but in reality it isn't quite that good. Some signals, like magnet currents are quite clean but others like the high-voltage power supply contain 10 volts of common mode noise and we also had to get rid of about 1/2 volt of 60 Hz noise.

WATERTON, AECL: Is the implication that, the majority of the noise is generated at the device you are measuring?

GORE, LASL: Yes. We have been able to keep our metering system fairly clean. The grounding bothered us but we have gone to double-ended multiplexers and can tolerate common made voltages as high as 10 volts.

NEAL, SLAC: I believe you mentioned that in the steering control of your prototype you don't have

DISCUSSION CONTINUED

position monitors yet, so that you are just maximizing the output current. In regard to the steering control with LAMPF, when you will have the position monitors and will you design the steering control to operate in a sequential manner or in a parallel manner?

GORE, LASL: It is currently planned to do this sequentially down the machine, i.e., to take a small beam and "nurse" it down the machine. We have not done any analysis to determine how one would set all of the magnets at one time. This would be a very good thing to do, I think.