Title

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Author

Machen, Donald R.

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INTRODUCTION

The generation of highly energetic elementary particles has progressed from the small-scale initial concepts on the physicist's laboratory bench into the realm of the large-scale "process plant"-- a plant requiring the coordinated skills of many scientists, engineers, and technicians. As the energy imparted to the elementary particles increases, the form and breadth of the control problem posed by these accelerators begins to take on the unmistakable appearance of a multivariable process control system.

In a recent design study (Ref. 1) of a 200 BeV Proton Synchrotron, undertaken by the Lawrence Radiation Laboratory for the Atomic Energy Commission, it was noted that the amount of control information required for efficient accelerator operation would preclude the practice of "hard-wire" transmission and continuous presentation of these control variables which is presently common practice in operating accelerators. Table I indicates the type and number of control variables and information expected in a machine of this energy range.

A solution to this problem, as offered in the 200 BeV Machine Design Study, is centered about the unique abilities of the stored-program digital computer. The digital computer can, with the proper algorithms, perform the function of a time-shared direct digital controller and operating-information processor for the central control area of such a machine.

Several accelerator laboratories throughout the world are beginning to touch on the digital computer as a process controller for machine operation, notably, Argonne and Brookhaven National Laboratories, Stanford Linear Accelerator Center (SLAC), and the European Organization for Nuclear Research (CERN) in Geneva, Switzerland.

DEVELOPMENTAL RESEARCH AT THE BEVATRON

The prospect of nearly complete accelerator operation via a digital control computer has been viewed with some skepticism by accelerator people. The concepts for control put forth in the 200 BeV Design Study are new to the accelerator field, even though several laboratories are planning to enter or have actually entered into limited automation with the digital computer as the central processing element.

The Berkeley Bevatron, a 6.2 BeV proton synchrotron, was selected as the archetype for developmental research in the area of direct digital control and operator-information processing and display. A scaled-down computer control system operating on the Bevatron would not only serve to corroborate the proposals made in the 200 BeV Design Study, but would also allow the Bevatron scientists to investigate the worth of computer-aided control as an adjunct to the present control system.

For the initial effort, a section of the Bevatron termed the Inflection System was selected for computer control. The inflection system is located between the linear accelerator and the main accelerating ring and serves to match to the main ring the proton beam emerging from the "linac." Figure 1 depicts the physical location of the inflection system and the various devices attached to it.

As noted in Fig. 1, there are steering magnets for both vertical and horizontal beam positioning, position monitors for vertical and horizontal beam position indication, triplet quadrupole magnets for beam matching and orientation in phase space, and inflector magnets for large-angle horizontal beam bending prior to beam entry into the main ring.

The preliminary control problem to be attacked is that of closed-loop regulation of the beam position between the exit of the linear accelerator and the entrance of the first inflector magnet. A program of this nature requires that steering-magnet currents be monitored and controlled and that beam position in two dimensions be monitored as feedback information. In addition, the quadrupole magnet currents and inflector magnet currents must be monitored and used in a logical check routine along with the main control algorithm. As experience is gained on the beam regulation program, the more difficult adjustment of the inflector magnets and the quadrupole magnets will be attempted. With these programs, the charge in the main ring must also be monitored as a final performance index to the control program.

DETAILS OF THE BEVATRON COMPUTER CONTROL SYSTEM

A system similar to that proposed for the 200 BeV synchrotron, but scaled down in size and complexity, was desired for the Bevatron experiments. Figure 2 depicts the form of the control system proposed for the 200 BeV machine. The interface elements entitled "analog" and "magnet" set point control, and analog monitor serve to disseminate and collect information necessary for logical control of the process. In order to provide complete system information to the operator and the computer algorithms, interface elements entitled "status monitor" and "on-off control" are also included.

Earlier this year, a PDP-5 computer was purchased for use as a direct digital controller at the Bevatron. Figure 3 shows schematically the details of interface for the Bevatron system.

This system will utilize two of the major interface subsystems proposed for the 200 BeV synchrotron—the analog monitor and the analog control subsystems. "Status" and "on-off" information will be handled within these two interface subsystems, as the Bevatron inflector control problem is much smaller than that foreseen in the 200 BeV synchrotron study. The logic will be essentially a time-shared multiplex system for both analog monitoring and control. Time sharing was dictated by (a) the number of monitoring and control points (25 to 30 each) and (b) the limited time involved in each acceleration cycle. Figure 3 also shows a typical acceleration cycle. The injection time (the time in which beam is within the inflector system) amounts to only 600 microseconds out of a 6-second acceleration period. Critical items such as beam position are monitored upon computer command by sample and hold amplifiers and then converted to a digital word in a sequential way during the rise time of the Bevatron field. Magnet currents are next monitored sequentially—some during acceleration and some after acceleration is completed, but before the next injection cycle.

As noted on Fig. 3, system interrupts to the computer are generated at injection, or the beginning of acceleration, and at completion of inversion, or the end of acceleration. Various control algorithms are initiated depending upon the interrupt involved.

Upon execution of the initial beam-injection interrupt, the interrupt denoted as 1st in Fig. 3, the computer will monitor all beam position signals and scale them to the proper normalized values. The quadrupole magnet currents are then set to a predetermined value and an initial check of beam deviation from the path center line is made. Should there be a deviation at the entrance to the first inflector magnet, a systematic check is made of each position, in each dimension, going upstream to the exit of the linac. When the offending steering magnet is located, its current is set first to a positive maximum and the beam position is read, then to a negative maximum and the position is read. Three injection pulses are required for this operation. The assemblage of beam position indications is then used in a convergence calculation to determine the appropriate magnet current for zero beam deviation from center line. This routine is repeated for each steering magnet until the beam is positioned properly. After completion of tuning, position monitoring continues, with the capability of retuning when necessary.

In addition to the control algorithms a group of service routines will be available to the operator. These routines will allow selections of groups of variables for visual display on a storage tube oscilloscope or on the teletypewriter. The operator may also change the course of the control program flow by appropriate commands, e. g., enabling or disabling the regulation routine, changing the variables monitored on each interrupt, etc.

INTERFACE DETAILS

For the initial control program (beam-position regulation) all computer input and output will be passed through the accumulator. In a later experiment, in which control and information processing will take place within a single acceleration pulse, data break mode will also be utilized.

The necessary logic for addressing both the monitoring and control devices, converting and sending monitored information to the computer, and sending control information to the remote area will be constructed from Digital Equipment Corporation "Flip Chips." A few items, such as the reed-relay multiplexers and reed-relay digital-to-analog converters, are constructed by the Lawrence Radiation Laboratory.

All information sent to and from the computer will be in serial words from seven to thirteen bits long, depending upon the function. Telemetering between the computer and the remote area is over twisted-pair shielded cable, transformer-isolated at each end and essentially in pulse-coded phase modulation form. There is, therefore, a 180° phase shift between a transmitted "one" and "zero." Because of the type of decoding required to re-form each bit at the receiving end, this type of bit encoding allows for a greater degree of noise immunity.

CONCLUSIONS

At present, the tuning of the Bevatron inflection system for beam position requires a great deal of time and effort on the part of the operating personnel. It was felt that computer-aided control of this portion of the Bevatron would not only reduce the tune-up time, thereby aiding Bevatron operation, but also provide an experimental facility for developmental research on computer control of accelerators in general.

The lessons learned and experience gained through a project of this nature will allow future machines of higher energy to be controlled in the most effective manner by digital computer systems.

ACKNOWLEDGMENT

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REFERENCES

1. 200 BeV Accelerator Design Study, Lawrence Radiation Laboratory Report UCRL-16000, June 1965.

FIGURE LEGENDS

Fig. 1. Bevatron inflection system.

Fig. 2. Control computer and telemetering subsystems.

Fig. 3. Closed-loop computer control of beam position: system schematic and timing (Berkeley Bevatron injection system).

Table I. Estimated number of control variables, proposed 200 BeV proton synchrotron.

Type of information or control	Number of points	
	Main synchrotron	Injector
Status information	11 500	6 500
On-off control	3 000	500
Analog monitoring	5 300	2 200
Set point control	2 200	300

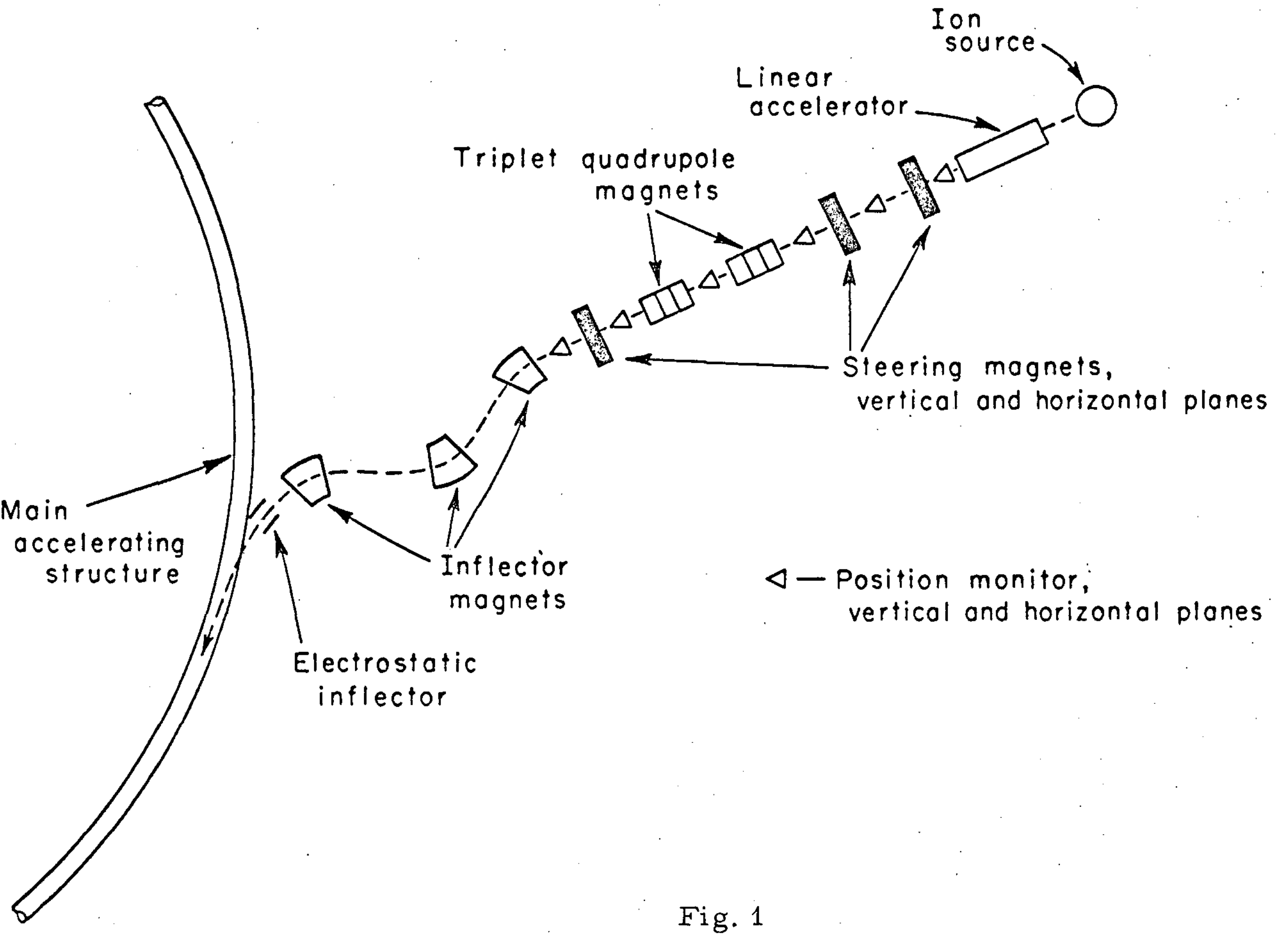

Fig. 1

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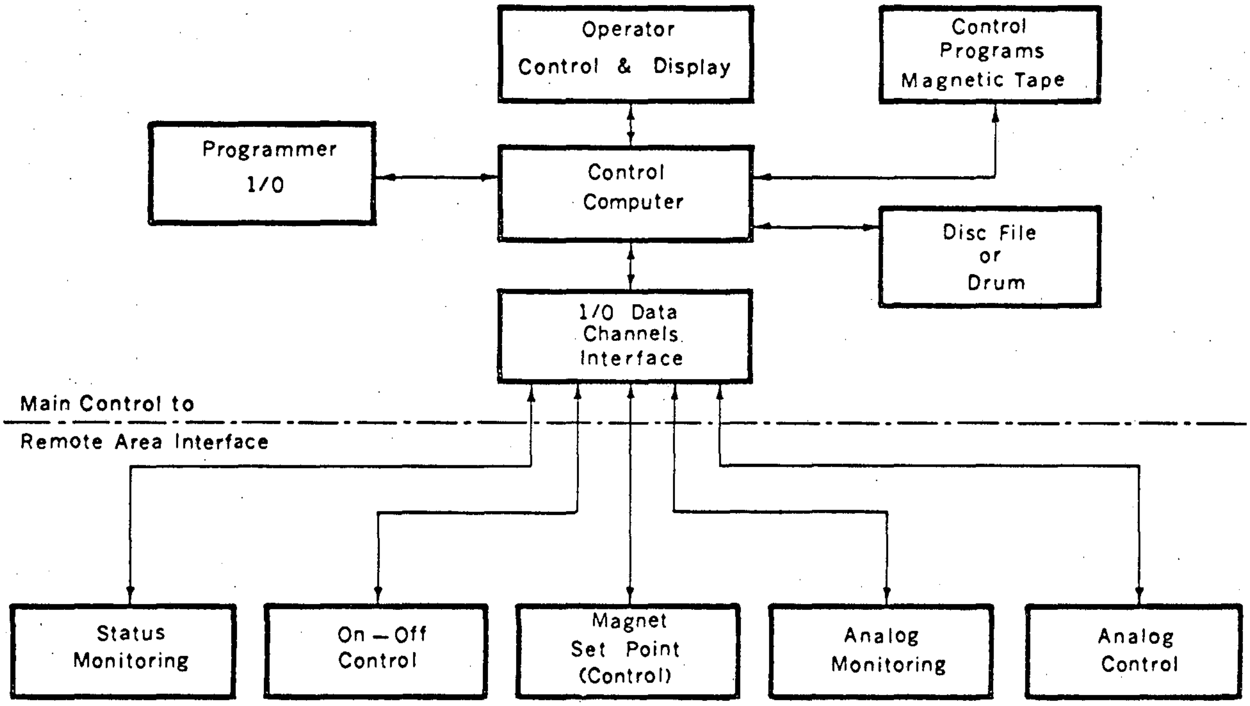

Fig. 2

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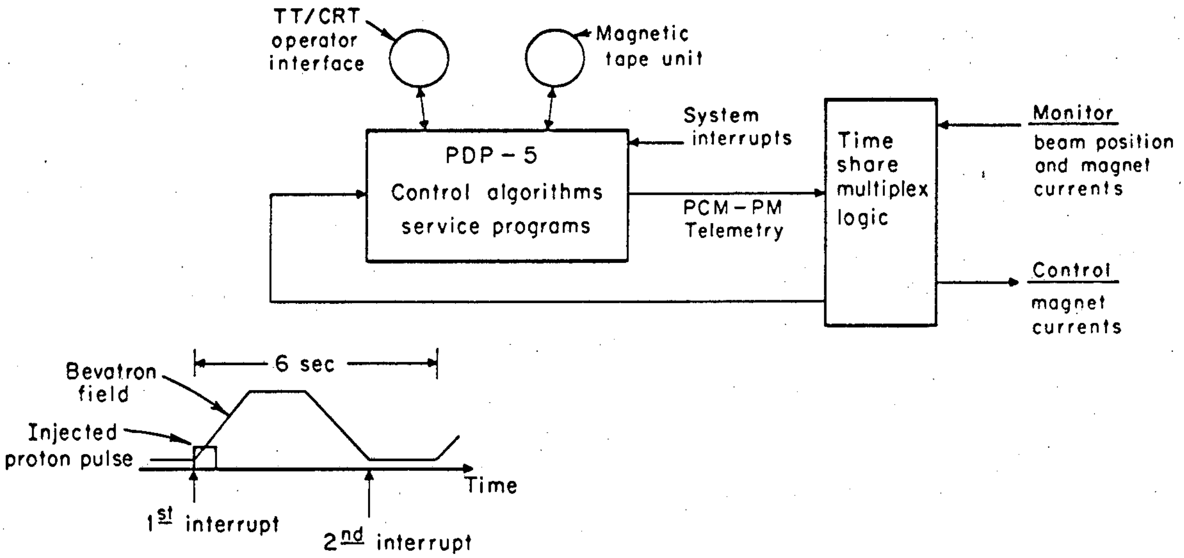

Fig. 3

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