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AN ON-LINE COMPUTER INSTALLATION AT LAWRENCE RADIATION LABORATORY, BERKELEY

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ABSTRACT

Much of the digital instrumentation around large experimental installations can best be provided by using a stored-program computer. The use of a small (PDP-5) computer in such on-line applications is discussed. Such a machine is especially valuable for readout, display, and graph plotting, and for reduction of data before input to a larger computer. It is also useful in the accumulation of new data.

A particular installation at the 88-inch cyclotron will initially provide for rapid transfer of information from a 4096-channel pulse-height analyzer. Simple calculations will be carried out on the data, using a CRT display and a "light pen" for easy operator intervention. The computer provides for program interruption by external devices, so that it will be possible to interlace a number of operations.

A method has been devised to allow efficient use of the 12-bit words of the computer in pulse-height analysis applications, where a few channels may contain many more counts than a 12-bit word could hold. The technique will also allow use of the computer as a derandomizer in high-speed pulse-height analysis.

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INTRODUCTION

The Lawrence Radiation Laboratory (LRL) at Berkeley is well known for its contributions to high-energy physics. Use of computers on-line for bubble chamber track processing has been reported previously,[1] and of course a large part of almost every high-energy physics experiment involves the treatment of experimental data by computers. Sypko Andreae and Roy Haddock have recently used a PDP-5 computer in high-energy physics experiments to provide on-line display of partially reduced data.

In addition to the high-energy physics work, a substantial part of the total LRL program is devoted to low-energy physics and nuclear chemistry. This paper deals exclusively with a system being prepared for nuclear reaction studies on the 88-inch variable-energy cyclotron. Only part of the system has been delivered yet, so some of this paper describes untested equipment.

The 88-inch cyclotron installation is based on the on-line use of a small computer, the PDP-5, together with two 4096-channel multidimensional analyzers. The decision to purchase a small computer was made initially on the basis of data-handling requirements that would have resulted a few years ago in the design of several specialized electronic units. These requirements included on-line graphical plotting of pulse-height analyzer data, preparation of paper tape for permanent-record storage, integration under peaks, location of centers of peaks (possibly by fitting of known shapes to peaks), and preparation of typewritten records of these reduced data. After studying methods of doing these operations we were surprised to find that a small computer, together with the peripheral hardware required to do the job, could be purchased for only slightly more than the cost of building the specialized electronic units.

It must be emphasized that stored-program machines can be more economical than wired-program machines, even on the basis of initial cost and for fairly small assemblies. For any machine as large as a two-dimensional analyzer, of which only a small number will be produced, the stored-program machine appears to have almost all the advantages. In addition to meeting present needs, the computer also has the potential capability to satisfy many requirements that cannot be foreseen at present.

The stored-program machine will also give the experimenter more direct control over his experiment, since he (or one of his assistants) can safely modify the control programs (with the knowledge that the original conditions can always be restored).

Modification of wired hardware, on the other hand, requires specialized skill and much more detailed knowledge of the apparatus; errors may be very hard to locate, so that one always has qualms about changing any working apparatus for fear that it will stop working. One can argue that, with the use of a simple programmed computer, much of the problem of apparatus design is reduced to a problem in logic, so that the experimenter can once again design — or at least understand — his own equipment.

THE 88-INCH CYCLOTRON COMPUTER INSTALLATION

Figure 1 indicates the main components of the installation at the 88-inch cyclotron. The installation will be in a room adjoining the main counting room, so that wired connections from presently existing apparatus can readily be made, and the experimenter can use the computer as just another piece of equipment. The physical size is about the same as a two-dimensional pulse-height analyzer. The central processor is shown in schematic form by Figure 2. The machine has 4096 12-bit words with a 6-μsec memory cycle time. A "data break" facility will allow direct access to any part of memory, and a "program interrupt" facility will allow external devices to request the attention of the computer when required.

It is expected that initially, only one experimenter at a time will use the computer, although the program-interrupt facility of the PDP-5 will allow several operations to go forward simultaneously. For example, the machine will probably be used simultaneously to acquire experimental data and to monitor the operation of the cyclotron, with alarms to the experimenter or cyclotron operator if running conditions change.

The computer will control the following external devices: digital graph plotter, typewriter, "micro" magnetic tape deck, typewriter input and output, paper tape input and output, and an oscilloscope that displays data in analog form. A "light pen" attached to the oscilloscope display will also allow direct selection of areas of interest for special calculations or readout. The PDP-5 can operate all these devices simultaneously.

Initially, data will be fed to the computer from one or both Nuclear Data two-dimensional analyzers. The computer is able to control any or all analyzer functions when a simple interface unit is used. Data can be transferred automatically in either direction, so that the storage, display, and readout facilities of the analyzer can be considered as an extension of the computer, or the computer can be considered as an extension of the analyzer. A particular point of interest in this respect is that the IBM compatible magnetic-tape unit associated with one of the analyzers will be available for computer output, so we will not be forced to acquire an additional magnetic tape unit.

PULSE-HEIGHT ANALYSIS WITH THE COMPUTER

The "data-break" facility of the PDP-5 provides direct access to the core memory without disturbing the continuity of the computer program. This allows use of the computer, with an analog-to-digital converter, as an independent pulse-height analyzer. Each event will be stored as a word in a small (perhaps 128-word) area of memory used as a buffer. On the average, this storage will add 12 μsec to the dead time of the analog-to-digital converter. When the small memory buffer is partly full, a computer subroutine will be invoked to add 1 to the data word corresponding to each of the stored events. This operation requires less than 35 μsec per event, and can go on concurrently with the storage (through data break) of additional events in the buffer area.

One unfortunate characteristic of the PDP-5 is its short (12-bit) word length. This means that for pulse-height analysis applications, only 4095 counts can be stored in one word. Of course, almost all pulse-height analyzer applications require 10^5 or 10^6 counts per channel, so one might expect to need two PDP-5 words per pulse-height analyzer channel. In fact, however, this is not usually necessary. Almost all pulse-height analysis at the 88-inch cyclotron is with pulses obtained from monoenergetic particles striking solid-state detectors. The full width at half maximum of the peaks on the resulting spectra approaches 0.1% of the full energy. Similar resolution is obtained when gamma-ray lines are observed by use of lithium-drifted germanium detectors. The result is that most spectra consist of a lot of high narrow lines, each occupying a few channels, separated by many almost empty channels. This means that by using core storage efficiently many more counts can be stored by a given number of cores than could have been done if we were obliged to use the wide peaks produced by scintillation counters. Efficient use of the memory is aided by the short word length. Only a slight penalty in speed is suffered if the following procedure is used:

Each pulse-height "channel" is assigned to one 12-bit computer word. A small area of memory is reserved for storage of information about channels that overflow. The "add 1" step, when a pulse event is stored, automatically indicates when overflow occurs. A subroutine is then invoked to deal with the overflow. The subroutine stores the address of the channel that overflows, in the small reserved area of memory, and stores in the word next to this address the number of times that the particular channel overflowed. Thus 24 bits of storage are available to any channel that overflows. At the end of a run, or for display, this overflow information must be sorted out, but this is well within the abilities of any computer. The time required to store the overflow is a small fraction of the total counting time, since an overflow can occur only once for 4096 counts. Although no prior knowledge is required of which channels may overflow, this method assumes that only a small number of channels will actually overflow. Otherwise the time taken to display and read out the overflow information would be prohibitive. In cases in which many channels will overflow, each channel must use two adjacent words, with consequent reduction in total number of channels available. The 12-bit word has the advantage that it allows much more complete utilization of the available memory capacity than would a longer word. The disadvantage is that average storage times are slightly increased and computation times are greatly increased.

OPERATOR CONTROL OF COMPUTER

The problems of two-way communication between the experimenter and machine are very important. Subroutines can be selected manually by starting the computer at an appropriate address. A more sophisticated procedure involves a selector subroutine that allows simple typewritten commands to select a program. However, for simple control operations that must be repeated frequently, most experimenters prefer a switch to turn or a button to press. For instance, use of a typed command to change display ranges would be quite laborious. We will allow most of the common routines to be selected by a wafer switch which, in turn, will feed a selection code to the computer to start the various programs. Information will be presented to the operator in turn by a cathode-ray tube display or by the typewriter.

CONCLUSION

To sum up, we have come to the following conclusions:

- The PDP-5 can be used as a high-speed pulse-height analyzer.
- The interface problem between the PDP-5 and a two-dimensional analyzer is relatively simple.
- For a special-purpose installation, a stored-program machine is likely to be less expensive than a wired-program machine, chiefly because so much design and engineering effort can be eliminated.

REFERENCES

1. R. I. Hulsizer, Nucl. Instru. & Methods 20 (1963) 384.

FIGURE CAPTIONS

Fig. 1. The computer installation for the LRL 88-inch cyclotron.

Fig. 2. The PDP-5 central processor.

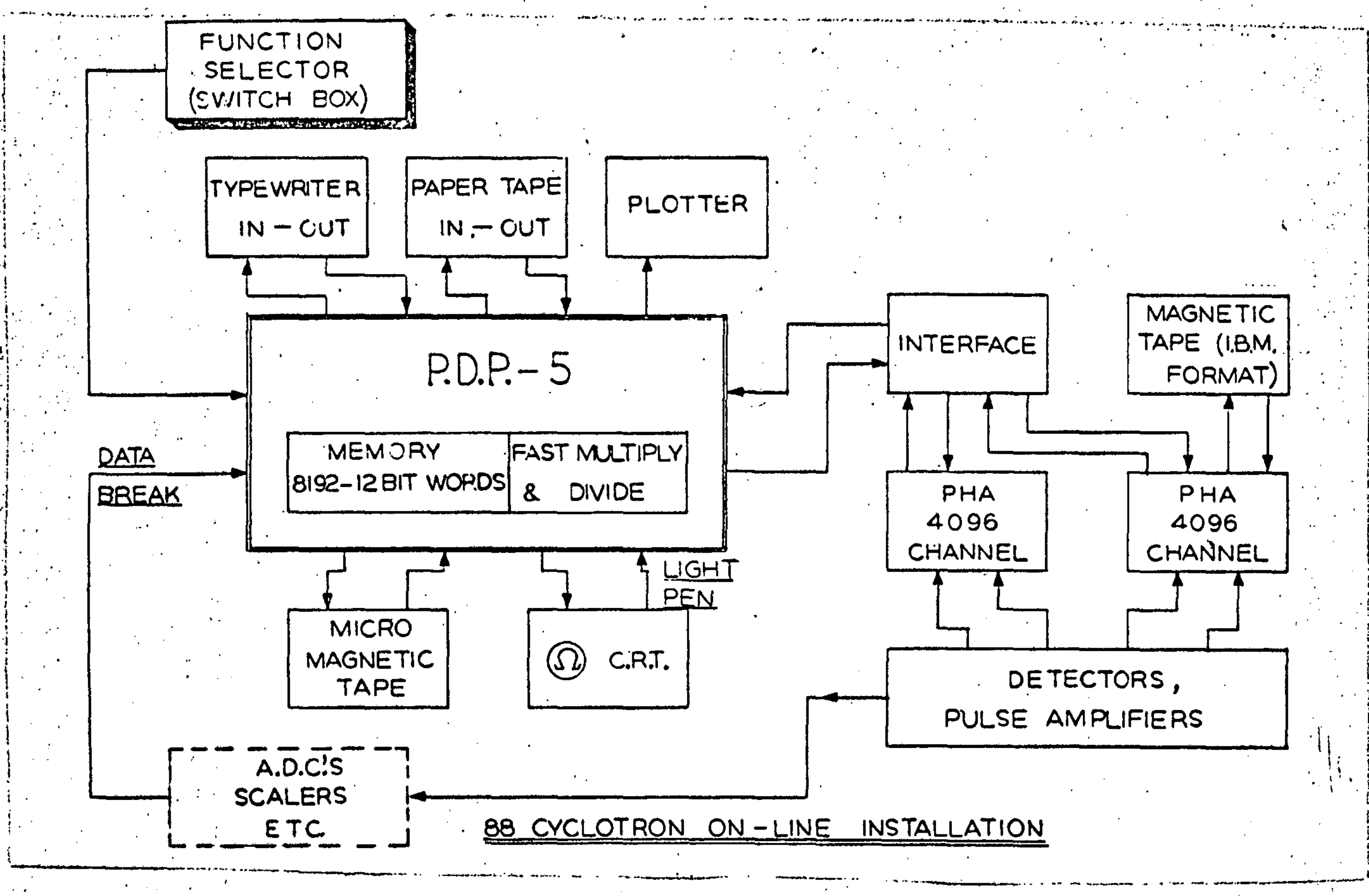
FUNCTION
SELECTOR
(SWITCH BOX)
TYPEWRITER
IN — OUT
PAPER TAPE
IN — OUT
PLOTTER
P.D.P.- 5
MEMORY
8192-12 BIT WORDS
FAST MULTIPLY
& DIVIDE
INTERFACE
MAGNETIC
TAPE (I.B.M.
FORMAT)
DATA
BREAK
PHA
4096
CHANNEL
PHA
4096
CHANNEL
LIGHT
PEN
MICRO
MAGNETIC
TAPE
C.R.T.
DETECTORS,
PULSE AMPLIFIERS
A.D.C.'S
SCALERS
ETC.
88 CYCLOTRON ON-LINE INSTALLATION

Fig. 1

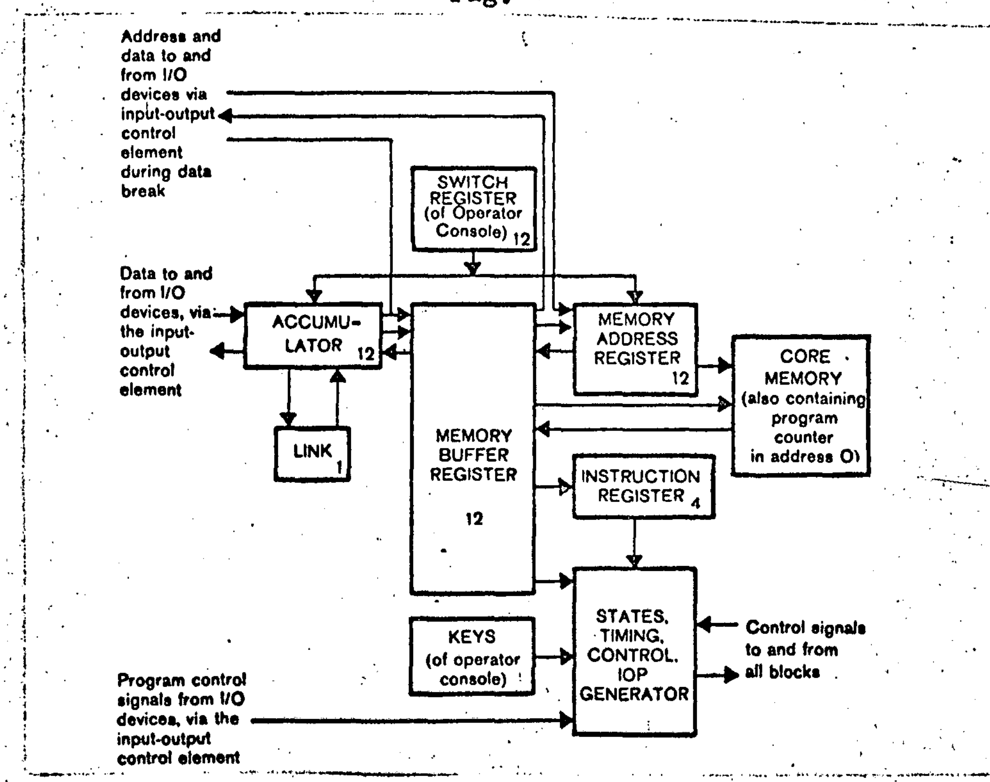
Address and data to and from I/O devices via input-output control element during data break
SWITCH REGISTER (of Operator Console) 12
Data to and from I/O devices, via the input-output control element
ACCUMULATOR 12
MEMORY ADDRESS REGISTER 12
CORE MEMORY (also containing program counter in address 0)
LINK 1
MEMORY BUFFER REGISTER 12
INSTRUCTION REGISTER 4
KEYS (of operator console)
STATES, TIMING, CONTROL, IOP GENERATOR
Control signals to and from all blocks
Program control signals from I/O devices, via the input-output control element

Fig. 2