EXPERIMENTS IN COMPUTER CONTROL AND ANALYSIS OF THE AGS*

R. Frankel
Brookhaven National Laboratory
Upton, N.Y.

Summary. The development, design and test of computer input/output devices and programing techniques suitable for use in accelerator analysis and control as well as criteria for the selection of computers acceptable for analysis and control work.

The effective use of a digital computer with an accelerator requires that a number of special purpose devices be developed whereby the pertinent parameters of an accelerator may be translated into a computer compatible format. At the AGS, we have designed and constructed a number of input/output devices for our PDP-8 computer such that an extremely broad range of signals or states may be adjusted and/or recognized. In almost all cases the required factor may be assigned to one of three major categories: Time, Voltage and Status.

Time refers to the ability to measure Frequency and Time Interval Data. The AGS has a number of pulse time parameters whose occurrence with respect to machine time is regulated within ten microseconds; it is desirable to know if a pulse varies in time or fails to occur. As the typical AGS cycle is 2.4 seconds any monitoring counter must be able to count to at least 2^{18} binary bits. In order to perform this measurement using conventional techniques, it is likely that an individual counter would be required for each pulse under observation. On the other hand, a computer serves as a high speed memory and allows us to employ a single counter connected so that the counter's instantaneous content is transferred to a preselected pair of memory locations upon the occurrence of the corresponding pulse. A pair of memory locations is necessary as the word length of a PDP-8 is only twelve bits. Using the data break (direct access to core memory) mode of entry to the PDP-8, it is possible to load two words in approximately 5 microseconds. Thus, provided only that the pulses occur at least 5 microseconds apart, it is possible to observe and record an indefinite number of time intervals for the cost of a single counter and computer input buffer. A feature of this unit is the use of a "single-shot" chain to store and reload any missed count pulses (100 KHz) lost because the counter must be held frozen during data transfers into the computer's memory. Analysis of operation characteristics also requires the ability to record the frequency of the radio-frequency system or of the orbiting particle bunches at any given instant of time. A computer controlled Frequency Meter has been constructed which may be interrogated at a given time in the accelerator's cycle, either by internal program control or external pulse actuation. It then counts for a preselected interval-one millisecond or one hundred microseconds-and upon completion signals the computer that the data is ready for transfer. As it takes a relatively long time to obtain the frequency of interest, data is not transferred under "data break" mode as in the Time Interval Meter but an operation called Program Interrupt is utilized. Program Interrupt, a feature available in most computers intended for control and monitoring applications, provides that upon the erection of a FLAG, or signal flip-flop, that the computer will conclude its present instruction, under program control store the contents of those registers necessary for the resumption of the interrupted calculation and jump to a subroutine specified by that particular FLAG. In this case it acts to store the requested frequency in memory.

Another category of input is Voltage; by the use of transducers many non-electrical inputs may be made to generate an analog voltage and, of course, electrical and electronic devices do so. A field-effect transistor multiplex switch and an analog to digital converter were designed to enable these signals to be processed. Electronic switching allows rapid reading of input channels and simplifies programing. Those signals which do not exist for the one hundred microseconds necessary to perform a channel selection and digital to analog conversion are buffered with F.E.T. Sample and Hold circuits. Digital signals need no conversion and our final system will contain BCD to computer interface equipment.

The final category of input is Status; typically Status refers to whether a unit is "on" or "off", "high" or "low", or perhaps has malfunctioned. Our system assigns each device being monitored a flip-flop. Whenever a device changes to "on" status the flip-flop is set. Each AGS cycle the associated registers are cleared, but if any device is "on" it immediately resets its flip-flop. The contents of the flip-flops in groups of twelve then are transferred into the computers memory for future analysis. (Note that Program Interrupt is not directly employed, but that the transfer is performed under program control at a time selected by a real time millisecond clock program, updated by Program Interrupt). Almost any number of devices may thus be monitored at the cost of a flip-flop each and some gates. It was not necessary for our application, but it is also possible to design the computer input buffer to react with Program Interrupt to a change in any flip-flop state and thus be able to determine the exact sequence in which a group of devices was energized or deactivated.

Thus far our discussion has been confined to monitor oriented devices. In order to control an accelerator the computer must be capable of providing voltages, pulses etc. A series of experiments presently undertaken will be able to utilize

*Work done under the auspices of the U.S. Atomic Energy Commission.

the following output devices: 12 channel pulse generator-generating accelerator standard pulses at program selected times-synchronized to the AGS cycle; 8 channel dual-cup motor controlled potentiometers, setable under program control and capable of remote location; a Digital to Analog converter able to generate arbitrary functions in real time under program control; and a computer activated relay facility for control or switching purposes. Members of the accelerator staff are presently engaged in programing the computer so that these devices may be used both for direct control of restricted sections of the AGS as well as in the automation of complicated AGS studies experiments.

The acquisition of accelerator parameters may be divided into two regions: Those parameters which occur at rates slow enough for the acquisition techniques previously described and those parameters typically relating to the structure, intensity and position of the orbiting particles which are available only for the briefest intervals. A multi-channel high speed successive - approximation Analog to Digital converter was constructed specifically for this purpose[1].

It soon becomes clear to anyone working in the field of computer control and accelerators that while the necessary input/output devices are somewhat complex they are within the "state of the art" in terms of technological achievement. However, the programing concepts necessary to monitor and control an accelerator with a small computer are not so well delineated. Our projects philosophy has been to program the operation of each device such that it will respond only when requested to respond, or when a condition occurs outside of certain predetermined limits. This avoids a major problem with many data-logging systems, e.g., separating significant data from routine normal-operation reports. Indeed, by the use of several teletypewriter links, specific information may be channeled only where it is desired. All programs are written so as to be compatible with a "monitor" program[2]. The "monitor" is so constructed that if it is provided time information via a sixty cycle and a one millisecond pulse train, it is capable of performing specific subroutines at selected times in the day and/or the AGS cycle. Another feature of the monitor system is its "job stack". Typically a program is written in two parts. The first, a much shorter section, performs a real time function such as a data transfer synchronous to a time in the accelerator cycle. It then places the address of the applicable analysis program upon the "job stack". The "job stack" (second part) is continuously being processed by the computer. This arrangement allows basic subroutines to be employed by all programs and provides for real time data handling under program control. As a twelve bit word length 4096 word computer has insufficient capacity to hold an effective FORTRAN compiler, programs are written in Assembly language and for similar reasons fixed point arithmetic is used. Assembly language programing is not significantly more difficult than FORTRAN and in the realm of real time problems may even be preferable. In evaluating a computer for suitability in a monitoring or control application particular attention should be placed upon the computers word length. Twelve bits places severe restrictions upon the amount of memory which may be directly addressed and hence upon the complexity of a program of even moderate size. In addition arithmetic problems performed with twelve bit words in fixed point arithmetic often require double precision handling.

It is interesting to consider a monitor or control computer not as a computer but instead as a infinite combination switch box. Program control allows the flexibility so necessary in control systems for constantly evolving devices such as accelerators. From an engineering and economics viewpoint, an excellent case may be presented for the utility and simplicity of a single computer control system versus a multiplicity of independent hard wired control and monitor subsystems. The ability to reduce any control headquarters to the size of a single teletypewriter and perhaps a single oscilloscope, coupled with memory capability for adaptive action, results in an uncrowded, sophisticated and easily operated control center, a very desireable creature even without the added ability of a computer to compute and correlate.

At the present time, the AGS is operating with the on-line assistance of a computer used as a monitoring tool-specifically in the areas of Time and Status. A number of programs are presently being developed which will attempt to employ the PDP-8 and its interface as a correlation device between accelerator parameters and control adjustments. Among the unique advantages of a computer control system is its ability to perform correlation control, as compared to regulation control obtainable from most servo subsystems. In conclusion, the worth of an on-line computer for accelerator use is just beginning to be established. The flexibility of our small, experimentally oriented, computer project is providing valuable insights into both the advantages and problems of computer control and analysis.

References

1. A. Alderman, R. Frankel, Injection Orbit Studies in the AGS, Natl. Part. Accel. Conf., 1-4 (1967).
2. M.Q. Barton, J.C. Alderman, PDP-8 Monitor Program, AADD Tech. Note 18, (1966).