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OPERATING EXPERIENCE WITH A NEW ACCELERATOR CONTROL SYSTEM BASED UPON MICROPROCESSORS*  
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Summary  
This paper will describe the design and operating experience with a high performance control system tailored to the requirements of the SuperHILAC accelerator. A large number (20) of the latest 16-bit microcomputer boards are used in a parallel-distributed manner to get a high system bandwidth. Because of the high bandwidth, software costs and complexity are significantly reduced. The system by its very nature and design is easily upgraded and repaired. Dynamically assigned and labeled knobs, together with touch-panels, allow a flexible and efficient operator interface. An X-Y vector graphics system provides for display and labeling of real-time signals as well as general plotting functions. This control system allows attachment of a powerful auxiliary computer for scientific processing with access to accelerator parameters.  

Introduction  
When computer control was installed at the SuperHILAC six years ago, the two injectors were left with analog controls because the difficulty and expense of controlling them by computer seemed greater than the payoff. The special problems associated with digitizing equipment at high voltage includes the difficulty of obtaining noise-free data transmission and the ability to operate the injectors for tests during maintenance periods when the computer system is likely to be shut down as well. Satisfying the second requirement could only have been done with parallel analog controls, because the minicomputer-based system used a central data base computer which would not have been accessible during computer maintenance periods. When the third injector was being planned, we realized that advances in computer technology had opened a way to solve the problem with minimum cost, with different hardware, which would, however, be compatible with the existing SuperHILAC control system.  
Thus the new third injector control system is entirely under computer control. The design philosophy and architecture of its microprocessor based control system have been described in previous papers. Here it should be sufficient to enumerate briefly the features of this system which we believe are new, particularly those which distinguish it from the more common minicomputer based control systems.  
- Use of a large number (20) of microprocessor boards, each executing a simple task, or a series of simple tasks.  
- In each chassis there are several processors operating in parallel.  
- Use of a distributed data base in ROM (read only memory), so that local, stand-alone control of accelerator components can be readily done.  
- Use of fiber optics, permitting high bandwidth, noise-free data transmission.  
- Modular construction, which permits easy expansion of control points and of effective memory.  
- Update and repair is easily accomplished.  
- Use of a de facto industry standard card cage and bus—the multiplex—which has a large number of suppliers of compatible components.  

Fig. 1 Schematic of system architecture.  

Fig. 2 shows schematically the major components of the system. Each of the blocks represents a card cage. The DMM modules interface to the accelerator equipment, collect and digitize data, and transmit control instructions to the hardware. The IOMM modules contain the local data base in ROM. The UMM module serves as a distributed collector for all data sent to and from the IOMM. It contains a copy of each IOMM data base. There is one processor in this unit for each 8 IOMMs; as more IOMMs are added, additional boards are added as necessary to the CPU to handle the increased traffic. The UMM modules are used to service the operator consoles. Their access to the CPU database is by means of a multiplex extension. This is a pair of boards designed in-house which extend the address and data lines from the CPU to the DMM. Several CPUs can be connected, in parallel, to the CPU. The three shown in Fig. 1 correspond to three control stations at the SuperHILAC, one for each injector. At present, injectors 1 and 2 remain under analog control—we plan to convert them to digital control in the near future.  

In the present paper we will focus primarily upon the DMM and associated operator console equipment.  

The DMM  

Fig. 2 shows schematically the computer boards used in the DMM at present—more can be added as needed. The alphanumeric display boards are used to write to the two CRTs. Output of the console touch screens is through the console computer board. A graphic computer board is used to support four vector graphic
displays. The operating computer is used to execute standard operating tasks, as well as to provide a link to a separate, powerful computer system which is used for a number of development activities. All of these computer boards have direct access to the data base in the OMM via the multibus extension.

SuperHILAC beams require frequent retuning, on the order of several times per week, because of changing circumstances. Consequently, knobs for operator use are important for this accelerator. Each CRT at the control station has 8 knobs, and each knob has a 12 character addressable LED for labeling the controlled device (see fig. 4). Alternatively, the device parameter value can be displayed in this space. Buttons located on the panel below the knobs are used to move a cursor on the CRT parameter list display, to scroll the list, to assign knobs to parameters, to change knob sensitivity, etc.

Fig. 2 Schematic of OMM configuration.

Operator Console

The portion of the console which is served by the microprocessor control system is shown in fig. 4. There are two control panels, each containing a CRT for displaying alphanumerics. These are overlaid with touch screens having a spatial resolution corresponding to the size of one character. Two 16-button pads to the right of each CRT allow entry of numbers and special commands. These input in parallel to the touch screens and give a little more flexibility for input. All commands could be given through the touch screens, but this would result in a great deal of wasteful paging back and forth in some cases.

Four vector graphic display units are mounted at each console above the touch panels. These units, in addition to displaying graphs with alphanumerics, allow mixing of real-time analog signals with the digital plots. This can be thought of as an oscilloscope with labels under program control. These signals are added to the output of the graphics translator using a chopper technique (see fig. 5).

Fig. 4 Closeup of touch panel CRT with associated controls.

Fig. 3 Photo of operator console.

Fig. 5 Schematic of video mixing of analog signals with vector graphics translator output.
adder also provides for limited changing of the gain and time base. In fig. 6 the display is an example of the use of this analog capability to present three wave forms from the ion source: extractor voltage, sputter current, and arc current.

Another important use for the portable console is to run accelerator equipment tied to the IOMM for checkout during maintenance periods, when the computer control system is also usually down for maintenance or for the installation of new programs, etc. Without such a local control capability, a full set of parallel controls would need to be installed for such critical equipment as in sources and RF, which require operation as an integral part of maintenance.

Finally, the portable console is provided with special programs and output plugs used to checkout and isolate problems associated with control system components such as multiplexers, timing modules, and graphics equipment independent of the IOMM.

System Limitations and Plans for Improvement

This control system meets or exceeds all of its design specifications. However, a very important test for any control system is its ability to adapt to new requirements. We will want to add many new controlled elements and many more beam monitoring devices to the present system. With a 30 Hz machine, requirements for data collection and analysis can grow to almost any limit. We would like for the system to be able to handle as much as possible. As the system grows in complexity, reliability considerations will demand memory protection, the ability for the computer to diagnose its own failures, and to fail gracefully. Fortunately, the microprocessor technology which we have chosen to follow is moving in this direction. It will be possible to meet all of these goals inexpensively with standard hardware and with modest software additions.

The currently implemented system can handle about 1000 controlled elements, each requiring 5 channels (such as analog control, analog monitor, etc.). A new board which will soon be available (incorporating Intel 1608/286) will allow us to handle more than 10,000 controlled devices. It will be 5 times faster than the present boards, will have a larger address space (16 megabytes), and will provide for memory protection. Where needed, computations can be speeded up by adding a math chip. We will redo the OMM so that all serial traffic is 5 times faster by using a single chip microcomputer for each channel. This will also eliminate all multibus traffic due to serial transmission. It will then be possible to put the serial transmission networking into firmware, with the consequence that the IOMM can write to the OMM just as if it were local memory. This will significantly simplify programming in the OMM.

With expected improvements in fiber optics links (100 megabits/sec) it will be possible to convert the OMM to IOMM connection to a serial bus. This will have the effect of making the IOMM appear to be on the OMM local bus, even though it may be thousands of feet away.

References

1. S. Magary et al., Proceedings of the 6th IEEE Conf. on Appl. of Accel. in Research and Industry, Denton, TX, Nov. 1500 (LBL-11761).
3. Multibus is a trademark of Intel Corporation.