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CONTROL SYSTEM FOR THE STONY BROOK SUPERCONDUCTING HEAVY-ION LINAC*

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Summary

The control system for the Stony Brook Superconducting Heavy-Ion LINAC is described. Familiar response characteristics and convenient operation have been given high priority in the design. A star network of 9 LSI-11 microcomputers forms the basis of the system which in addition comprises a PDP 11/34 minicomputer, one 6502 microprocessor-based RF controller for each of 43 resonators, and several I/O devices such as graphics display and reassignable control knobs.

I. Introduction

The Stony Brook Superconducting Heavy-Ion LINAC project is well into the construction phase at the present time[1]. This report describes the design of the network of computers and interface electronics which will control the 43 independently-phased superconducting resonators, liquid helium refrigerator and cryogen transfer system, and some 30 magnets of the beam transport system of the LINAC.

An effort has been made to ensure that in those instances when real-time interactive control of some device is called for the system's speed of response should be sufficient to render the computer network essentially transparent to the operator.

A star configuration of 9 LSI-11 microcomputers provides the basic structure upon which the control system is built. Six of the 8 satellite LSI-11/2's are devoted to resonator control, one is associated with the cryogenics system, and one serves the beam transport system. In addition, a PDP 11/34 computer handles extensive numerical calculation, high volume data storage and retrieval, and is available for system development. At the center of the star a LSI-11/23 manages the flow of all information among the various elements of the system. In particular, the central element of the operator-computer interface is a color-graphics video display terminal equipped with an overlaid touch-sensitive membrane, both of which are connected to the central LSI-11/23.

Re-assignable rotating control knobs are used for manipulation of analog type parameters whereas binary and digital parameters are set via the touch screen and a small dedicated keypad. A standard typewriter keyboard is also available for entering non-routine commands.

Six channels of real-time analog signals from each resonator control circuit are switched by the satellite computers to the control console for metering and oscilloscope display.

II. Subsystems

Resonators: Each resonator is controlled by a dedicated stand-alone microprocessor-based control unit. This, unit, designed and built by the Low Temperature Physics group at Cal-Tech[2], employs direct RF feedback to achieve phase and amplitude stabilization to a level of ±0.1° and ±0.1%, respectively. The important advantage of direct RF feedback is the absence of active devices at cryogenic temperatures for reactance switching. A down-conversion/up-conversion technique is used, in which all control signals are manipulated at intermediate frequencies (IF)<200 kH$_z$, where analog function circuits and analog-digital interface circuits are readily available. Complete information describing the instantaneous state of a resonator is contained within the set of IF signals, therefore eliminating the necessity to switch any RF signals to the control console. The MOSTEK 6502 microprocessor based resonator controller handles all RF-IF feedback parameter adjustments either locally through front panel switches or remotely via an 8-bit parallel interface to one of the 6 module control station LSI-11's. An 8-channel 8 bit ADC module enables the μP to monitor the status of a resonator and make some adjustments automatically, or issue messages via the computer network requesting operator assistance.

Module Control Stations: The LINAC is composed of 16 low-β resonators, grouped in four cryostat modules, and 24 high-β resonators in eight modules. Support electronics are further consolidated into 6 module control stations, each serving two modules. Two injection pre-bunchers and one post-acceleration de-buncher are controlled from high-β module control stations. Each module control station contains one of the eight LSI-11/2 satellite microcomputers, which manage nearly all aspects of the modules, including local video display of resonator parameters.

Cryogenics: The cryogenic cooling requirements of the superconducting resonators are fulfilled by a 400W turbo-cool 100 refrigerator. The refrigerator and a complete cryogen transfer system have been fully operational for some time. Manual control of the refrigerator is envisaged throughout the initial phase of operation, with control system activity limited to parameter monitoring and logging. Considerable operational experience with the LINAC and refrigerator will be required before reliable algorithms are obtained to implement closed loop computer control of the refrigerator. The cryogen transfer system, on the other hand, utilizes computer control from the outset to actuate delivery valves and maintain proper levels of liquid nitrogen and liquid helium in the cryostat reservoirs. Liquid levels are monitored continuously by simple level gauges which exploit well the potential of the distributed processor computer network.

Beam Transport Magnets: The 12 cryostat modules of the LINAC are each separated by a compact room temperature quadrupole doublet. Available space considerations dictate a 180° isochronous turn in the LINAC injection path. This turn is made up of two 90° dipole magnets separated by a quadrupole triplet. One additional quadrupole doublet in the injection beam path is among the magnets to be controlled by the LINAC control system. In all, the beam transport system requires programming voltages and current/voltage read-back capacity for 30 power supplies. Fault detection interlocks are, of course, all hardwired to the power supplies although status information of interlocks is entered into the computer system.

Vacuum: For the beam line vacuum system the computer control system plays an essentially passive role, since all interlocks are locally-closed hardwired loops. Valves can be actuated from the control console after satisfaction of all interlocks. Vacuum levels and valve status are read by the module control station LSI 11/2's for presentation at the control console.

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III. Control Console

Two identical and independent operator stations are provided at the control console. Each station relies heavily upon two continuously rotating control knobs. A unit has been built in-house which interfaces the knobs to the computer via a standard DEC parallel interface. The knobs, connected to incremental shaft encoders, drive hardwired up/down counters, thus permitting fully asynchronous operation and giving significance to the absolute position of the knob. Three display fields accompany each knob; alphanumeric for parameter identification, a four digit field for knob position, and a four digit field for parameter readback. A small dedicated keypad is also incorporated into the control knob electronics module.

The primary control device is a color video display screen with an overlaid touch-sensitive membrane. The color display is the character graphics type, well suited for process control where speed of generating a display is more important than subtleties in the displayed image. The color dimension also plays an important role. Besides indicating status of certain parameters it is used to make the identification between a control knob and a controlled quantity. The Aydin Controls Model 5217 video display generator and a Barco 13" video monitor were chosen for the system. The Aydin unit has the ability to store simultaneously four pages of display and switch instantly from one to another. By preloading the most likely next selections in a tree structure scheme the latency period can be greatly reduced.

The touch screen from Sierracin/Intrex Corporation provides a continuous analog readout with a resolution of ±0.1". The analog nature of the device implies that the boundries of the touch buttoms are completely arbitrary and can be defined by the software to fit the graphics, not vice versa.

Observation of real-time analog signals from the resonator controllers is invaluable in phase-locking and adjusting the resonators. An "analog bus" system provides these signals to the control console. The system has a bandwidth of DC to 1 MHz and gain of 1±0.01. Six IF signals from the resonator controllers are switched under computer control to each operator statation. They are received differentially in a custom built plug-in unit for a Tektronix model TM500 mainframe. The plug-in contains a calibrated analog meter for indicating RF field level and a signed frequency counter for determining the resonator natural frequency with respect to the LINAC master oscillator. Also in the TM 500 mainframe are two dual trace oscilloscopes. The format for the display of the six lines is fixed, e.g., line one always goes to scope one channel one, etc.; line 5 goes to the analog meter and line 6 is a spare. This fixed format significantly reduces the complexity of the switching network, but more importantly, it eliminates the operation of setting up the display set, since the analog bus automatically follows the touch screen assignment. Mixed resonator displays are allowed by typing explicit commands to the computer.

IV. Computers

Figure 1 shows the interconnection scheme for all the system computers. The LSI-11/23 situated at the control console is in contact with all the other computers and all the console I/O devices. It has the full 128 K words of memory and 5 M bytes of hard disk storage. The satellite computers, LSI-11/2's, operate with 32 K words of memory and no disks.

The six LSI-11/2 satellite computers located in the module control stations are linked to up to eight resonator controllers via 8-bit parallel I/O channels. Several other analog and digital I/O channels are used to service other aspects of the module control station. For example, forward and reverse RF power levels for each resonator are detected with directional coupliers (designed and built in-house). These power levels are converted via a 32 channel 12 bit ADC unit and entered into the data pool. Two other LSI-11/2's control the beam transport magnets and cryogenics system.

All LSI-11 computers are acquired as parts of commercial computer-based process control units (ADAC Corporation System 1000). This unit was selected primarily because the system is supported by an extensive line of essentially turn-key interfacing cards. This selection has allowed us to keep the demand for production of special purpose electronics commensurate with the available facilities.

All the computers in the network utilize some form of the popular DEC real-time, multitasking RSX operating system. The PDP 11/34 and LSI 11/23 both run RSX-11M V3.2 mapped operating systems. The LSI-11/2's, since they lack any mass storage and memory management hardware, run the memory resident RSX-11S V2.0 unmapped operating system which is downloaded from the LSI-11/23. Initial program loading of and subsequent communications with the satellite processors proceeds via the same RS422 full duplex asynchronous serial line, which can operate at speeds up to 19.2 K band.

All network software was designed and written in-house. A key part of this software is a device driver tailorable for either RSX-11M or -11S which implements the low level message protocol and physical device control for both down-line loading and routine message transfer. A down-line loader transfers the RSX-11S operating system task image from the LSI-11/23's disk to one of the LSI-11/2's for execution. Further communication with tasks running on the satellite LSI-11/2 takes place using a simple variable length message protocol designed for low overhead and ease of implementation.

The use of the RSX operating system on all of the PDP and LSI computers not only provides a compatible foundation for program development for all machines, its multitasking capabilities encourage a structured, modular approach to software development. The programming language 'C' has been chosen as the standard language for program development since it provides high level structured language capability while allowing essentially assembly language speed and versatility.

System generation and program development for all of the computers in the system takes place primarily on the multiuser PDP 11/34. As the project proceeds out of the construction phase and further into routine operation the PDP 11/34 will be used in an additional support capacity of running beam dynamics codes to assist the operator in determining the optimal setting of beam related parameters.

V. Status

The design phase of the control system is basically complete, with all the conceptual designs frozen and all the major hardware items specified and ordered. Detailed design and construction continues on in-house projects such as the analog bus. Systems software work is essentially complete and downloading of programs written in C to the satellite computers is routine. The phase of applications programming is underway with some important programs already in use. For example, the magnets of the 180° turn have been operated from the control knobs via the computer network for several months.

The availability of a PDP 11/60 computer, on a temporary but full-time basis, has allowed the systems development work to proceed to such advanced stages prior to the delivery of some important system components such as the LSI-11/23.

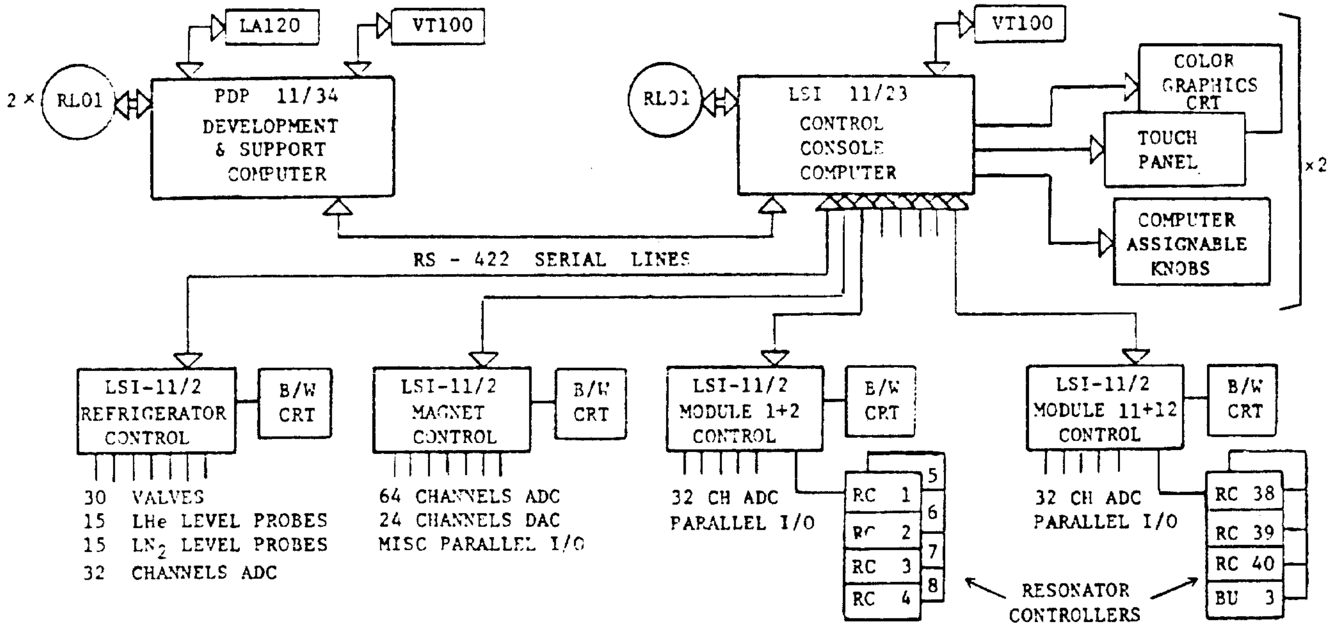

Fig. 1: Computer control network showing the central LSI-11/23 and four of the eight LSI-11/2 satellite computers. Peripheral devices indicated are: RL01=5 M byte hard disk, LA120=hardcopy terminal, VT100=CRT terminal.

It is clear that the many months of effort invested in constructing a solid systems foundation will shortly be rewarded by a timely and prolific period of applications programming.

References

1. I. Ben-Zvi et al., these proceedings.
2. J. R. Delayen et al., IEEE Trans. Nucl. Science NS-24, p. 1759 (1977).