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UPGRADING THE FERMILAB LINAC LOCAL CONTROL SYSTEM

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Introduction

A new control system for the Fermilab Linac is being designed, built and implemented. First, the nine-year-old linac control system [1] is being replaced. Second, a control system for the new 805 MHz part of the linac [2] is being built. The two systems are essentially identical, so that when the installations are complete, we will still have a single Linac Control System.

Replacing the Old Control System

The old control system, commissioned in 1982 and detailed in reference [1], is incompatible with our controls plans for the upgraded linac. The old system, based on locally designed and built components using Multibus-I, an 8MHz MC68000 cpu board and the SDLC network, is difficult to expand, to maintain and to integrate into the more modern system envisioned for the new linac.

The design criteria of the replacement control system are:

1. Retain the desirable features of the old system, including local access to the equipment and the monitoring and reporting of of the local information at the repetition rate of the accelerator, 15 Hz. (In particular, if a reading goes out of tolerance, the control system can disable beam on the next pulse.)

2. Minimize the software effort,

3. Use commercial hardware as much as possible,

4. Limit the amount of downtime necessary for the changeover.

In order to minimize the software effort, the same system used in the DØ high-energy physics experiment at Fermilab [3], which itself is based on the existing linac control system, is being used. Essentially nothing needs to be changed to use this system, although some features have been added. The DØ control system is quite large, so the relatively small linac control system will not require very much additional effort, except during commissioning.

The replacement system for the existing linac is shown schematically in Figure 1. Its major features are outlined here. The IEEE 802.5 Token Ring network connects a series of VMEbus

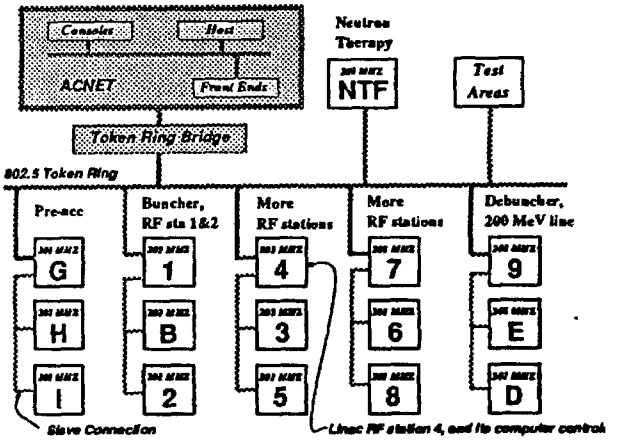

Figure 1, Upgraded controls for the existing Fermilab Linac.

† Operated by the Universities Research Association under contract for the Department of Energy.

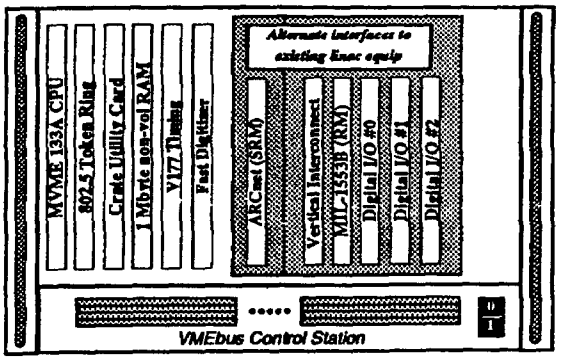

Figure 2, Typical VME station in the Upgraded Controls for the Linac

crates to each other and, through a bridge, to the rest of the Fermilab accelerator complex. The VME crates contain the hardware necessary to connect to each other (token ring) and to control the existing linac hardware, see Figure 2. Contained in each crate are the following core set of VME cards: a cpu card, the MVME133A; a token ring card; a crate utility card; and non-volatile RAM. Other I/O will also be used. Because the new system has been designed to handle up to 2000 analog channels, it is not necessary to have a new system for each old RF station. A ratio of one computer control station for every three RF stations has been adopted.

We are considering two ways to interface to the old linac hardware, as suggested in the grey box of Figure 2. The first way, Figure 3a, is to use three commercial, six-byte digital I/O cards configured to match exactly the old system's eighteen-byte I/O scheme. This scheme requires that a VME crate be located near the digitizing hardware. Two of the crates would be slaved to the first by linking the VME memories. A VME card has been developed to give limited memory access to several remote VME crates from a master crate. This card is called a "vertical interconnect" or VI. It maps 16 Mbyte blocks of VME memory (24-bit addressing) into each of four digital crates. As many as 24 slave crates are served from six VI master cards in a single local station. For each control station there are two additional VME crates. Each of the three VME crates contains the digital I/O cards necessary to interface with the old hardware.

This method has been successfully tested on the extra 201 MHz RF station in the linac. The RF stations which now have a Multibus-based 12-bit D/A board (used for dipole magnet set-

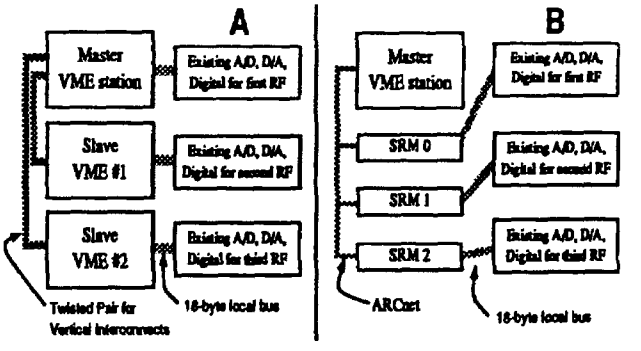

Figure 3, two ways to connect to the old linac hardware

tings) would be equipped with a Rack Monitor (RM). The rack monitor, as built for DØ, contains eight twelve-bit D/A channels, 64 (unheld) twelve-bit A/D channels, four 16-bit words of digital I/O and a MIL-STD-1553B interface. A 32-channel sample-and-hold chassis would be needed to use the digitizer on the RM. The rack monitor gets its name from the fact that the interface to all the equipment in a 19-inch rack can usually be made through one RM.

The second method, Figure 3b, uses a new Motorola chip designed to control a modern automobile engine, the MC68332 microcontroller. This 68020-based chip includes sixteen counter/timer channels, a serial communications interface, two kbytes of RAM and a system integration module. This processor is available as a small subsystem called a Business Card Computer (BCC), a 2.25 by 3.5 inch circuit board that has the MC68332, 128 kbytes of PROM, 64 kbytes of RAM and an RS-232 serial interface.

We would incorporate this BCC into a new type of rack monitor creating a Smart Rack Monitor (SRM, [4]). The BCC would attach to the motherboard of the SRM through its two 64-pin DIN connectors. All the address, data, control and I/O pins of the MC68332 are available on these two connectors. Included on the silicon of the chip is an extensive system integration module—a collection of interface features normally provided by peripheral chips. A SRM would add the following functions: Tevatron-style clock decoder, ARCnet local-area network interface to the VME master, eight bytes of digital I/O, sixteen-channel D/A, twelve-bit S&H A/D and a 64-channel analog multiplexor. We have designed new nine-byte digital I/O daughter cards to communicate with the old linac equipment. Two would be needed for each SRM.

The control system alternative with SRM's would be less expensive, more powerful and faster than the other alternative. Unfortunately, we do not yet have a clear idea of how to write the software to drive the SRM.

Changeover Plans

The decision as to which type of interface to use is imminent. When the decision is made, we will order the hardware necessary to convert completely the old linac control system to the system described above. We will assemble the new stations at their final locations, load the appropriate local data base and perform thorough testing off-line before the actual changeover. We anticipate it will take less than a week to perform the switch, but, naturally, we expect a somewhat longer unstable period. We hope to have the new system for the old linac installed by the summer of 1991. This new system will remain in place, controlling the old linac, for about a year. The last four tanks of the old linac, along with that part of the control system, will be removed as the new linac is rolled in.

Control System for the New Linac

The new linac addition at Fermilab is detailed elsewhere at this conference [1]. The major aspects of that system are as follows. The H- beam exiting tank five, at 116 MeV, is captured by an 805 MHz transition section and injected into a seven-module side-coupled-cavity accelerating structure. The 805 MHz modules fit in the space vacated by our old tanks six through nine which now accelerate the beam to 204 MeV. The beam in the new structure is accelerated to a final energy of 401 MeV. This higher-energy beam is easier for the next accelerator, the Booster, to handle because of a 75% reduction in the space-charge tune shift there. The two small transition section cavities, the seven large accelerating modules and the debuncher cavity are powered by 805 MHz klystrons. The seven accelerating modules each use a 12 MW klystron under development by Litton; the other three smaller cavities are driven by a pulsed-version of a UHF-TV channel 69 80-kW-cw klystron.

The following control system is being built for the 805-MHz part of the new linac, see Figures 4 and 5. The control stations are connected to each other and to the rest of the world by token ring. The system interfaces with hardware subsystems either through a VI to a slave VME subsystem or through rack monitors (smart or dumb). Each control station manages two major systems, usually two klystron RF systems. A color console is located at each control station to give local access to the information.

There are several distinct subsystems in each RF station. Modulator and low-level RF computer-controlled subsystems are being developed. Conventional water systems, beam diagnostics and safety systems are also being built. How each of these interfaces to the control system is described here [5].

The modulator and low-level RF subsystems both contain a smart controller in, respectively, VME and VXI environments. Communications occur through VME memory over a VI. Each smart subsystem will perform its own A/D and D/A conversions. The local intelligence of these systems will provide the pertinent digitized readouts in a contiguous block of VME memory which the master control station can read, over the VIs, at 15 Hz. A similar block of contiguous memory will be provided by each

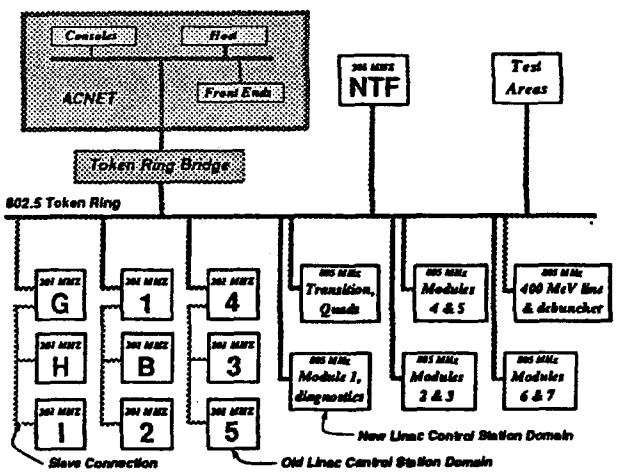

Figure 4, The controls system for the Upgraded Linac

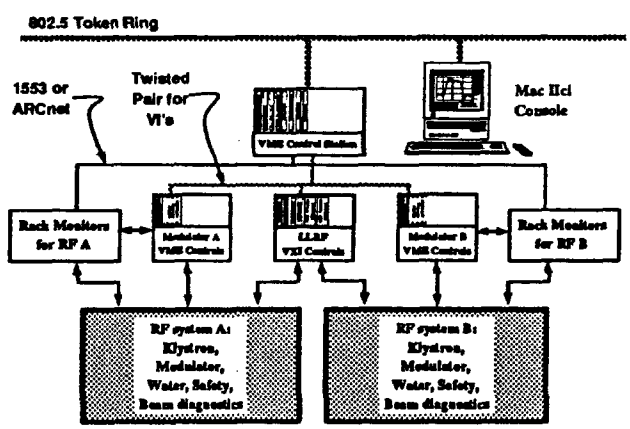

Figure 5, Detail of a single control station for the new Linac.

system for making settings.

The modulator provides a 180 KV, 141 ampere, 128 μs pulse to the klystron. It appears to a Linac control station as, simply, a self-regulating, self-protecting high-voltage power supply. The control station generates a 16-bit voltage setting for the modulator system. Several analog and digital readbacks are provided. The local intelligence for the modulator is responsible for:

1. 15 Hz closed-loop control in the modulator;

2. 15 Hz readout of local analog and digital information;

3. transient recording of pertinent waveforms within the hardware;

4. fast closed-loop/feed-forward control to insure that the proper level of voltage regulation (0.1%) is obtained.

One VME crate per modulator, two per control station, are necessary for noise suppression. The transient waveforms are sorted according to the condition of the modulator—most are recorded as "good" waveforms, but the real purpose of this capability is to access the waveforms generated during a failure of the modulator. These waveforms can be accessed in the VME memory of the modulator crate over the VI. Although the amount of data stored for these transient waveforms is large (several MBytes), it is thought that the frequency they are viewed will be small.

The low-level RF hardware runs in the VXIbus environment. This system is responsible for providing an RF signal of the correct phase and amplitude to the 500-watt klystron-driver amplifier so that beam is properly accelerated through the cavity. The local VXI microprocessor will generate and adaptively change that waveform according to phase and amplitude information obtained from recent beam pulses: "adaptive feed-forward." Two klystrons will be fed from a single VXI crate containing two low-level RF hardware modules. As discussed above, readings and settings to this system from the master control station will be done through VME/VXI memory over a VI.

The beam diagnostics [6] provide several analog signals which are read through a sample-and-hold/RM. Since the aperture of the new linac is significantly smaller than the old linac (3 cm vs 4 cm), we are going to implement a local application (see below) to actively keep the beam in the center of the beam pipe. It is likely that a local application will also be needed to assist with the measurements for the "Δt" experiment [7].

The interface to the klystron interlocks/safety system is through several (twenty) bits in a RM at each RF station. A computer-reset and a computer-ready bit are provided. (Naturally, the primary safety aspects of the accelerator are contained in the hardware. The computer controls system is not part of the safety system.) The water system interface is through a RM.

Also present at each control station is a color computer console. This console uses the Macintosh IIci computer with an Apple TokenTalk Nubus card. The applications presently available are a color parameter page, a parameter plotting package and a VME memory-dump page. These programs are quite mature and reflect the standard Macintosh "look-and-feel." Additionally, we have a token ring driver to the LabView package[8].

Software Features

Several aspects of the local controls software need to be mentioned explicitly. The software is being developed to have each local station respond directly to data requests generated from the consoles in the Main Control Room, thus eliminating the need for a protocol-translating front-end computer. These consoles communicate via the Accelerator Controls Network (ACNET) protocol which the other accelerator controls subsystems at Fermilab use. Each Linac control station is to recognize two sorts of network message protocols, the original ("classic") protocol, used in communication between control stations, and the ACNET protocol.

A critical part of the control station software is supporting multiple, simultaneous, local control procedures. Each local station now has the ability to run many "Local Applications," or LAs. The LAs being implemented now include:

1. 201-MHz system recovery, *e.g.*, from a modulator crowbar;

2. DTL quad reset;

3. 805-MHz system water temperature stabilization (note: there will be four cavity water systems and a klystron water system for each RF system: that's ten water loops per control station),

4. beam steering;

5. 805-MHz turn-on and turn-off;

6. low-energy emittance scan.

The software for the smart rack monitor is not settled yet. The MC68332 is based on the MC68020, so most, but not all, of the instructions of the '020 are in the '332. The hope is that we can implement simple but extensible software on the '332 which allows, initially, the SRM to behave like a dumb RM. Then, features could be added to support SRM local applications.

Conclusions

The control system for the Fermilab linac has been redesigned. The old linac control system is to be replaced in the summer of 1991 by one similar to that required to operate the 805 MHz/400 MeV linac. The old D/A and A/D hardware is retained on the old RF systems. The control system for the new linac requires some new techniques, in particular, interfacing with several smart subsystems. The two types of local control are designed to work together to control the whole new linac in a coherent, integrated and efficient fashion.

References

[1] R. Goodwin and M. Shea, "The Distributed Control System for the Fermilab 200 MeV Linac," Proceedings of the 1981 Linac Conference, pp 277-280.

[2] R. Noble, "The Fermilab Linac Upgrade," this conference, talk MO2-02.

[3] R. Goodwin, *et al.*, "Initial Operation and Current Status of the Fermilab DZero VMEBUS-Based Hardware Control and Monitoring System," proceedings of the 1989 International Conference on Accelerator and Large Experimental Physics Control Systems, Vancouver, BC, Canada.

[4] M. Shea, "Smart Rack Monitor," internal note, available from the authors.

[5] The modulator, low-level RF and safety systems are in the design phase. The best reference so far on these systems is found in the design report for the 400 MeV Fermilab Linac.

[6] "Diagnostics for the 400 MeV Fermilab Linac," Elliott S. McCrory, Glenn Lee and Robert Webber, this conference, talk number TU4-1

[7] T. Owens and E. McCrory, "The Delta-t procedure at Fermilab," at this conference, paper TH4-51.

[8] This product is available from National Instruments in Austin, TX. Additionally, a Unix interface to the token ring VME data has been written and a parameter page, plot package and a token ring driver to the DataViews package, available from VI Corporation in Amherst, MA, have been written. The Unix software is somewhat more capable, but a lot less mature than the Macintosh software.