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R. G. Bork
R. J. Kane
T. L. Moore

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APPLICATIONS OF SMALL COMPUTERS FOR SYSTEMS
CONTROL ON THE TANDEM MIRROR EXPERIMENT-UPGRADE*

R. C. Bork, R. J. Kane, and T. L. Moore,
Lawrence Livermore National Laboratory, University of California
Livermore, CA 94550

Summary

Desktop computers operating into a CAMAC-based interface are used to control and monitor the operation of the various subsystems on the Tandem Mirror Experiment-Upgrade (TMX-U) at Lawrence Livermore National Laboratory (LLNL). Small computers offer several advantages: independent system operation and development is possible, a modifiable operator interface is provided, and control and monitoring capabilities can be expanded as required without making major software modifications. System availability and reliability can be increased using spare computers and subassemblies. In addition, TMX-U experience has shown that very high programming efficiency is possible. Less than 10 man-months of software development were required to bring eight systems to the present level. These systems include: shot sequencer/master timing, neutral beam control (four consoles), magnet power system control, ion-cyclotron resonant heating (ICRH) control, thermocouple monitoring, getter system control, gas fueling system control, and electron-cyclotron resonant heating (ECRH) monitoring. Two additional computers are used to control the TMX-U neutral beam test stand and provide computer-aided repair/test and development of CAMAC modules. These machines are usually programmed in BASIC, but some codes have been interpreted into assembly language to increase speed. Details of the computer interfaces and system complexity are described as well as the evolution of the systems to their present states.

Introduction

Small computers play a major role in the control and monitoring systems on TMX-U, as can be seen in the computer system layout in Fig. 1. With the exception of a single large computer system designated for

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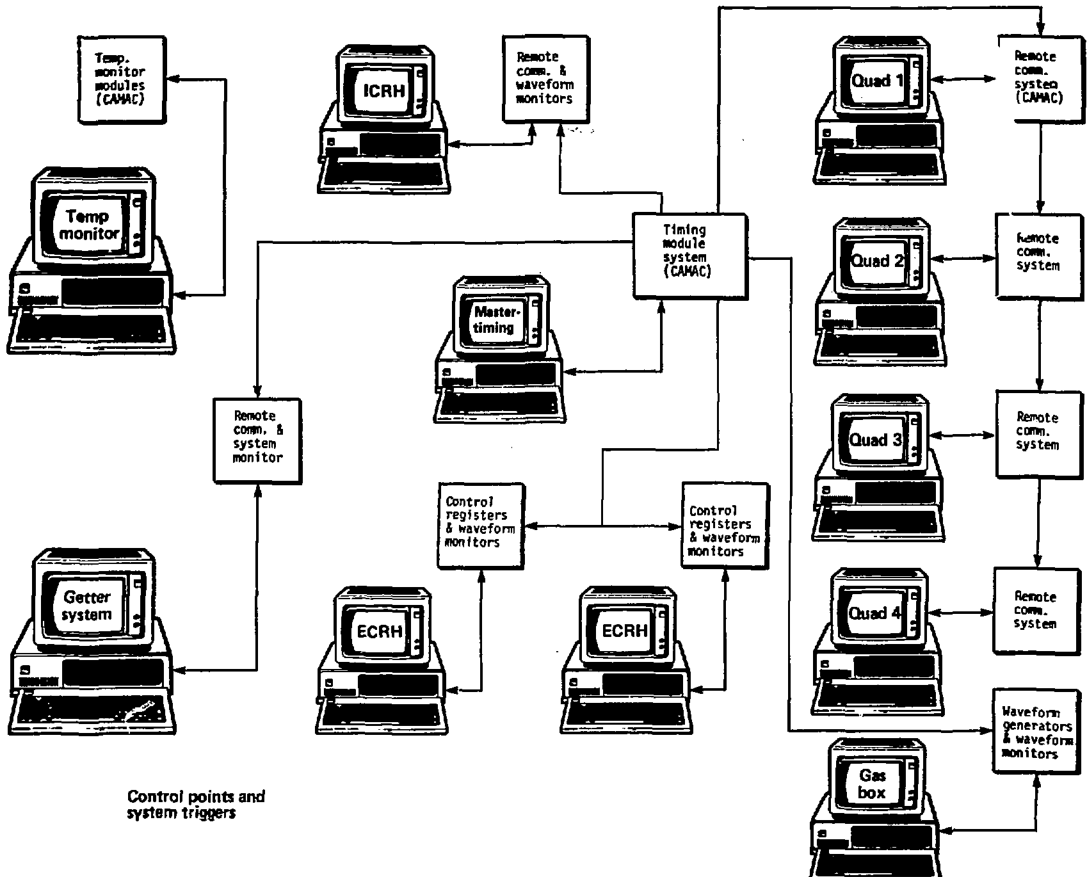

Fig. 1. Distributed computers and CAMAC system.

diagnostic data acquisition, virtually all of TMX-U's operating and monitoring systems use small computers. The systems vary in complexity from small monitoring systems such as a thermocouple recorder to large central systems such as the neutral beam control and magnet power control systems. The small computers vary in sophistication from a 32-kilobyte (kB) desktop calculator up to a 2-megabyte (MB) 32-bit multi-tasking desktop computer. We discuss several of the major systems that use these computers, pointing out their features and the evolution of small computer use.

Neutral Beam Control, Magnet Power Control, and Shot Sequencer Systems

Neutral beam control, magnet power control, and the shot sequencer systems were among the first systems designed for small desktop computer control on TMX-U. All three systems use a common-type 192-kB computer with a computer-automated measurement and control (CAMAC) interface system. Two additional computers were obtained for offline testing and debugging of software and CAMAC hardware as well as for the operation of the neutral beam test stand. Computers were brought into these systems to update the systems' control hardware run with TMX as well as to improve their reliability. The use of small, stand-alone computers vs a central system has allowed for independent development and testing. In addition, in the event of a computer failure, only one system or subsystem is lost to the experiment. The two offline computers mentioned also provide for ready spares, keeping down time to a minimum.

These systems use HP BASIC as the primary programming language. HP BASIC is much like FORTRAN with powerful I/O and interrupt features. BASIC lends itself to ease of initial programming and future modifications. In use, a high programming efficiency was also noted with all three systems being programmed to an online status after six man months of combined programming effort. All programming was performed by the system hardware design engineers and technicians.

BASIC did have a drawback in that it is relatively slow in operation. These control systems are fairly complex, and added speed of operation was desired. For this reason, portions of these programs, particularly the input/output section, were converted to assembly language. They were first written in BASIC, tested, and debugged, then compiled to assembly language using a BASIC-to-assembly utililty program. For the computers used, assembly allowed a 50-fold increase in speed over BASIC in the sections converted. Since the BASIC-to-assembly utility is limited in its syntax translation and mathematics capabilities, none of the programs has been wholly converted.

An example of these systems, their capabilities, and complexity are depicted in Fig. 2. The neutral beam system on TMX-U consists of 24 injectors with their associated power supplies. Small computers are used to control these power supply systems, each of which contains a high-energy storage bank and regulator system for accelerator voltage along with decelerator, arc, and filament power supplies. The system is designed to deliver 20 MW of power at 20,000 V.

One minicomputer controls and monitors a group of six injector systems. In addition, one on-board CAMAC microprocessor is used in the high-energy storage master control/monitor crate to manage the data link between the capacitor banks and the four beam computers. Each computer is thereby linked via fiber optic serial highways to 16 CAMAC crates with their 110 CAMAC modules. In addition, six real-time fiber optic data links provide power-supply time sequencing.

Each computer allows an operator to turn on/off control power and high voltage and to select a desired

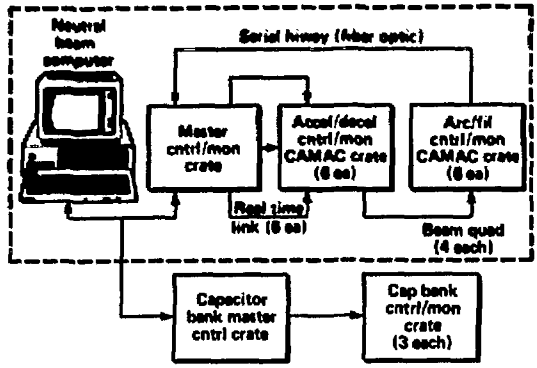

Fig. 2. TMX-U neutral beam control system.

accel and decel voltage, arc current, quick interrupt shut off number, and the power-supply sequence timing and configuration of the six beams under its control. Neutral beam shots may either be initialized locally or control-switched to master timing. The operator is provided with 66 system status items, which are read by the program in a quiescent loop from the CAMAC network and updated for display every 0.6 s. This loop also monitors the serial highway system and high-energy bank control/monitor microprocessor for proper operation, shifting to maintenance subroutines in the event of a failure to attempt to correct problems and alert the operator.

Upon completion of a beam shot, each computer gathers the shot data from the CAMAC network, calculates the accel voltage/current, arc voltage/current, filament voltage, total beam "on" time, and the number of quick interrupts that occurred during the shot. These data along with the time, shot number, and requested parameters are then displayed to the operator and filed on magnetic tape. The beam request parameters are then retransmitted to each of the beam systems and verified in preparation for the next shot. When all beams are triggered to fire simultaneously from master timing, this operation is completed in a nominal 6 s.

The neutral beam system has been online for two years. The original software has been modified a minimum amount, usually for operator convenience. Because of the system's independence and the use of BASIC, modifications were quickly and easily performed. The system has proved to be reliable and maintainable. In addition, downtime due to failure has decreased an estimated 70% from the previous control system used to operate neutral beams on TMX.

The magnet power supply control and shot sequencer systems are similar in their basic use of CAMAC interfacing and structure to the neutral beam control system. The magnet power control system has a single minicomputer to control 42 power supplies on 17 circuits at 24 MW. The quiescent loop in this system monitors magnet temperatures, water flow, and safety interlocks; checks for ground faults; turns on/off power supplies; sets up current regulation levels at operator request; and reports system status. This loop time is approximately three seconds. After receiving a shot command, the computer checks ground faults, turns on the 42 power supplies, sends current settings to the programmable supplies, holds the command for three seconds, turns the supplies off, and returns the current, voltage, and ground fault data for printout.

Another feature of this program, an advantage of computer control used on other systems as well, is self-calibration. Upon completion of a magnet shot, the measured and requested currents are compared and the power supply control commands are automatically adjusted to maintain the delivered current at requested values.

The shot sequencer computer is used to select and set in the timing of TMX-U systems on master timing. Currently, 11 systems and 38 subsystems can be individually selected from the console with 90 timing channels available. Master timing consists of 30 three-channel downcounter CAMAC modules tied to a common clock. These modules are loaded with the proper timing sequence and triggered simultaneously by the shot sequencer console. This system points up another advantage of using small computers for control systems, that of a modifiable operator interface and ease of expansion of control and monitoring capabilities. The shot sequencer/master timing originally consisted of eight selectable systems with 27 subsystems and 66 timing channels available. As more systems came online and timing channels were required, 24 timing channels were added. The shot sequencer computer was also assigned to control/monitor the neutral beam getter system. To accommodate these additions, the operator interface displays were revised and control sections were added to the original program. This was completed in three man weeks.

Progression to Other Systems

The successful operation of the above control systems and the advantages realized led to the use of minicomputers on other monitor/control systems. These include the gas fueling control system, plasma potential diagnostic system, ECRH monitor, and ICRH control system. These systems employ manufacturer-updated versions of the computers used in the systems discussed above with 2-MB memory and dual floppy disc drives.

The ECRH monitor computer is used primarily to gather the telemetry from the eight arm waveguide couplers, correct information according to crystal calibration factors, and display average output power to the system operators. For ICRH, the minicomputer is tasked to control and monitor a 2.5-Mhz, 200-kW transmitter, allowing the operator to enter the desired power levels, trigger the transmitter when commanded by master timing, and compute and display forward/reflected power at the ICRH antenna.

In the gas fueling control system, a minicomputer is used to calculate, adjust, and record gas flow into the plasma region of the TMX-U vacuum vessel through eight piezoelectric valves. To accomplish this, the operator enters the desired flow rate, which is converted by the computer to a waveform and loaded to a CAMAC programmable function generator. A command from master timing sends the waveform to programmable power supplies to regulate the opening of the valves. Pressure sensors at the valves return data to a CAMAC data recorder. The data are then read by the computer to calculate flow rate. The computer records, displays, and uses these data to make adjustments as necessary when loading the waveform for the next shot.

The latest system to employ a desktop computer is the machine getter control system. This system has been previously controlled as an analog metering arrangement. With 162 power supplies each having up to six getter wires, monitoring and data keeping becomes a large task for the operator. Therefore, we decided to update this system to provide computer control as well. This time, a 2-MB, 32-bit, multi-tasking desktop computer with a 10-MB internal disc was chosen.

The program is once again written in BASIC, which is run-time compiled, then run by the computer. With the multi-tasking capability of this computer, three programs are used in operation and run simultaneously. One program allows for operator interface in the operation of the getter system, one program handles all of the computer/CAMAC input/output operations, with constant update and monitoring of the power supplies, and one program is used to interface getter system performance data to the user. The primary reason for separating the programs was to allow the I/O program to run uninterrupted by operator interfacing.

With the high speed of a 32-bit processor, the current and voltage of the 162 supplies can be read, corrections calculated, adjustments made, and system error checked every 0.5 s. A large mass storage area is required as the voltage, current, shot number, and time of each getter cycle are logged for each power supply and getter wire, with the expected lifetime of each wire running as high as 300 to 400 cycles. In addition, operator notes are logged, power supply and wire status are updated and recorded, and wire performance graphics, daily summaries, and status reports are generated.

Conclusion

Small computers have proved highly effective and efficient on TMX-U. Their system independence, low system failure rate with minimum downtime/systems lost to the experiment when a failure does occur, ease and efficiency of programming, modifiable operator interface, and desirable processing speeds have made the small computer the mainstay of TMX-U control and monitoring systems.