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# THE ORNL 25 MV TANDEM ACCELERATOR CONTROL SYSTEM*

Raymond C. Juras, John A. Biggerstaff and David E. Hoglund**

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

The CAMAC-based control system for the 25 MV tandem electrostatic accelerator of the Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory (ORNL) was specified by ORNL and built by the National Electrostatics Corporation. Two Perkin-Elmer 32-bit minicomputers are used in the system, a message switching computer and a supervisory computer. The message switching computer transmits and receives control information on six serial highways. This computer shares memory with the supervisory computer. Operator consoles are located on a serial highway; control is by means of a console CRT, trackball, and assignable shaft encoders and meters. Two identical consoles operate simultaneously: one is located in the tandem control room; the other is located in the cyclotron control room to facilitate operation during injection of tandem beams into the cyclotron or when beam lines under control of the cyclotron control system are used. The supervisory computer is used for accelerator parameter setup calculations, actual accelerator setup for new beams based on scaled, recorded parameters from previously run beams, and various other functions. Nearly seven years of control system operation and improvements will be discussed.

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**Co-op student, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

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## 1. Introduction

The Holifield Heavy Ion Research Facility (HHIRF)[1] is located at the Oak Ridge National Laboratory and is operated as a national user facility for research in heavy ion science. The facility operates two major accelerators: a tandem electrostatic accelerator designed to operate at terminal voltages up to 25 MV[2] and the Oak Ridge Isochronous Cyclotron (ORIC) which is capable of operating as an energy booster for the tandem accelerator.

The present facility is the result of a project begun in 1974. The project included construction of the tandem accelerator (fig. 1) and modification of the ORIC to accept tandem beams for further acceleration. The project was completed in 1982, after which routine operation of the facility began.

Since we planned to operate the tandem accelerator and the ORIC both as separate stand-alone accelerators and together in a coupled mode, it was deemed important to have tandem consoles in two locations: the first in a "tandem" control room provided to serve several newly constructed experimental areas for tandem-only operation and the second in the existing ORIC control room for use in coupled operation and tandem-only operation with beam lines under control of the cyclotron control system.

A computer-based control system was decided upon[3,4] to ease the implementation of two control consoles, to reduce wiring costs, and to provide an inherent expansion capability, greater flexibility, and a more manageable ground-loop situation. The intent of the control system design was not to provide automatic control of the accelerator, but only to multiplex operator control and monitoring. It was hoped that eventually software would be written to relieve the operators of some tasks.

## 2. Hardware

The tandem accelerator control system is CAMAC based; it consists of 16 CAMAC crates on six bit-serial highways (see fig. 2). A Message Switching Computer (MSU) is used to multiplex control information between the control consoles and the controlled and monitored components. The MSU shares a memory with the Control and Supervisory Computer (CSC); the CSC is available for higher level control functions and for development of MSU and CSC software. In addition, programs are run on the CSC to calculate ORIC set-up parameters.

The control computers are Perkin Elmer 32-bit minicomputers. We have recently upgraded these computers from model 7/32 to model 8/32D. Each computer has 3/4 MBytes of local memory. In addition, the computers share 160 kBytes of memory. The MSU computer has a direct memory access (DMA) interface to two local CAMAC crates; the crates contain serial highway drivers for the six CAMAC highways. The CSC has general purpose computer peripherals (e.g. line printer, tape drive, etc.) and supports terminals at each control console and at various other locations in the facility.

Six of the control system CAMAC crates are located in gradient-free regions of the tandem accelerator column structure and operate at voltages up to 25 MV. Two crates are located in the negative ion injector and operate at voltages up to 550 kV. Communication with these crates is provided by infrared light links. Kinetic Systems 3932 U-port adapters are used to biphase-encode data and clock signals for the CAMAC serial highway so that only one signal must be transmitted and received from each CAMAC crate at elevated potential. The biphase encoded signals are transmitted at 2.5 Mbps across the 11-foot radial gap between the accelerator column structure and pressure vessel viewing ports. In the injector, the signals are transmitted along the injector grading column and then from injector deck potential to ion source potential. Any light link may be bypassed from the control console in the event of failure.

The tandem accelerator and, to a lesser extent, the injector are susceptible to large voltage transients (sparks) which are potentially damaging to the electronics. Particular attention was given to shielding of electronic components operating at elevated potentials. All signals into and out of the CAMAC crate pass through transient protection circuits. To date, few electronic failures are known to have been caused by sparks.

## 3. Control consoles

With the exception of a few high bandwidth signals, such as beam profile monitors and nuclear magnetic resonance indication of field strength in bending magnets, the control consoles are CAMAC based; both consoles are located on a 5 Mbps serial highway. Operator control is provided by means of a console CRT display and trackball, and "assignable" knobs and meters. In addition, the operator has dedicated displays for a few parameters such as accelerator terminal voltage and terminal potential stabilizer parameters (fig. 3).

To control a discrete parameter (i.e., on/off or forward/reverse), the operator locates the proper CRT "page," moves the cursor to the appropriate label by means of the trackball, and presses the "DO IT" button. To control a variable (i.e., a power supply voltage), the operator locates the proper CRT page, moves the cursor to the line on which the variable's label appears, and presses an "assign" button next to one of three knobs on the control console. The variable's label appears above the knob and by turning the knob the operator may change the variable. Each knob also has a "sensitivity" control which selects 2, 4, 8, ..., 4096 turns full scale, and "save" and "restore" buttons. The save button is a useful feature that allows the present setting of a parameter to be saved before it is changed; if an adjustment only makes matters worse, the original setting can be quickly returned via the restore button.

To monitor a parameter, the operator selects the proper CRT page and reads the value; readings are updated about once a second. He may also choose to move the cursor to the line on which the parameter appears and press the assign button next to one of the three "assignable" meters on the console. The parameter's label then appears above the meter and the meter displays the parameter's value updated 50 times per second. He may also press the assign button for one of eight analog jacks. A zero to ten volt signal is then available on a BNC connector for connection to a strip chart recorder or oscilloscope.

One panel of the control console has an array of lights labeled with CRT page numbers. If an alarm condition occurs, one of the lights illuminates. The operator selects the indicated CRT page; the alarm appears on the page with a red background. If the alarm is not urgent, the operator may "acknowledge" the alarm by moving the cursor to the position of the alarm; the background color changes to yellow and the alarm panel light extinguishes so that other alarms on that page may be seen. When an alarm condition clears, the alarm is automatically reset and rearmed.

## 4. Software

The software on the MSU provides the console functions described above. The software is based on two-time intervals: 500 milliseconds and 20 milliseconds. Every control parameter in the system is updated at least two times per second; the value of each parameter is contained in shared memory. Selected parameters (i.e. meters) are updated 50 times per second; the 20 millisecond updates are via a buffer in MSU local memory. Thirty-two characters of the selected CRT page at each console are formatted and sent out every 20 milliseconds. This results in an update of the CRT pages about once per second.

The software on the MSU is written in FORTRAN and assembly language. At the beginning of the project, the Perkin-Elmer FORTRAN compiler did not produce efficient machine code, so that extensive use was made of in-line assembly language in FORTRAN subprograms. In the past ten years, Perkin-Elmer has improved its FORTRAN compilers. The optimizing compiler now produces machine code that is nearly as good as a proficient programmer, but in-line assembly language interferes with the optimization process; all subprograms are now either FORTRAN-only or assembly-language-only (about 50% of each).

The CSC computer is available for software aids to operation, development of MSU software, and for calculation of ORIC set-up parameters. The standard Perkin-Elmer operating system is used on this computer. Because every parameter of the control system is available in shared memory and updated twice per second by the MSU, programs to aid accelerator operation are straightforward to implement. A program on the CSC simply writes to a data location in shared memory; that control information is sent to the controlled device within 1/2 second. When a CSC program reads a data location in shared memory, the information is never more than 1/2 second old.

One of the most useful software aids to operation is a program for recording tandem parameters and setting up new beams from scaled recorded parameters. Whenever a beam is successfully tuned through the accelerator, a program is invoked to record machine parameters into a disk file. About once a month, the file is searched for particularly good setups which are transferred to a "reference" file. All other setups are culled. The reference file is a fixed length file which contains a selection of the best machine tunes. When it is time to set up a new beam, the reference file is searched for conditions approximating the desired beam. The recorded parameters are scaled to the new energy and ion, and the ion optic elements (with the exception of bending magnets and the terminal voltage) are set automatically.

Another useful program keeps a continuous history of accelerator parameters. Every three minutes, the program records operating parameters into a disk file. Old information is selectively thrown out, so that the older information represents longer intervals. The recorded information is useful in spotting trends.

Several programs are provided for control of bending magnets. One program scans the output of the ion source by recording the beam current on a Faraday cup following the mass analyzing magnet as the magnet current is varied. The various mass peaks are identified for the operator. Another set of programs cycles the energy analyzing magnets to avoid hysteresis effects when beam energy is decreased.

Other aids include programs for recording and printing operating parameters on command, calculation of theoretical lifetimes of stripping foils, calculation of dispersion and energy loss due to stripping foils, and calculation of tandem set-up parameters for manual setup — including predicted charge-state fractions after the strippers.

In addition to facilitating tandem accelerator operation, the CSC is used to precalculate ORIC acceleration parameters. The calculations are based on the results of an extensive mapping of the ORIC field undertaken in 1977. The predicted settings frequently result in extracted beam; only minor tuning adjustments are required to optimize the beam intensity. Indeed, it would be difficult to use the ORIC as a post accelerator for tandem accelerator beams without this set of programs.

## 5. Maintenance

Since the control system is essential for accelerator operation during scheduled operation (21 shifts/week, totaling almost 4000 hours last year), quick maintenance is important. The control system will operate with only the MSU on-line; the CSC thus may serve as a backup. In addition, we have obtained a surplus computer of the same type as the two control computers. This computer insures that spare computer parts are operational and allows us to repair and check out computer components without disrupting operations.

Because only a few different models of CAMAC modules are used in the control system, only a small number of modules must be kept as spares. Failed modules are repaired using a microcomputer-based test station. Maintenance records are kept for each module, so that troublesome modules can be detected even though they are shuffled about the control system.

## 6. Conclusion

The computer-based control system for the tandem accelerator has proven to be flexible and reliable. The tight coupling of the control computers by means of a shared memory has made it possible for individuals with little knowledge of the control software in the MSU to contribute valuable application programs.

## 7. Acknowledgements

We wish to express our appreciation to staff members of the National Electrostatics Corporation for their work on the control system. We also wish to thank P. K. Kloeppel and K. A. Erb for their work on software aids to accelerator operation and T. P. Cleary who wrote the programs to pre-calculate ORIC parameters.

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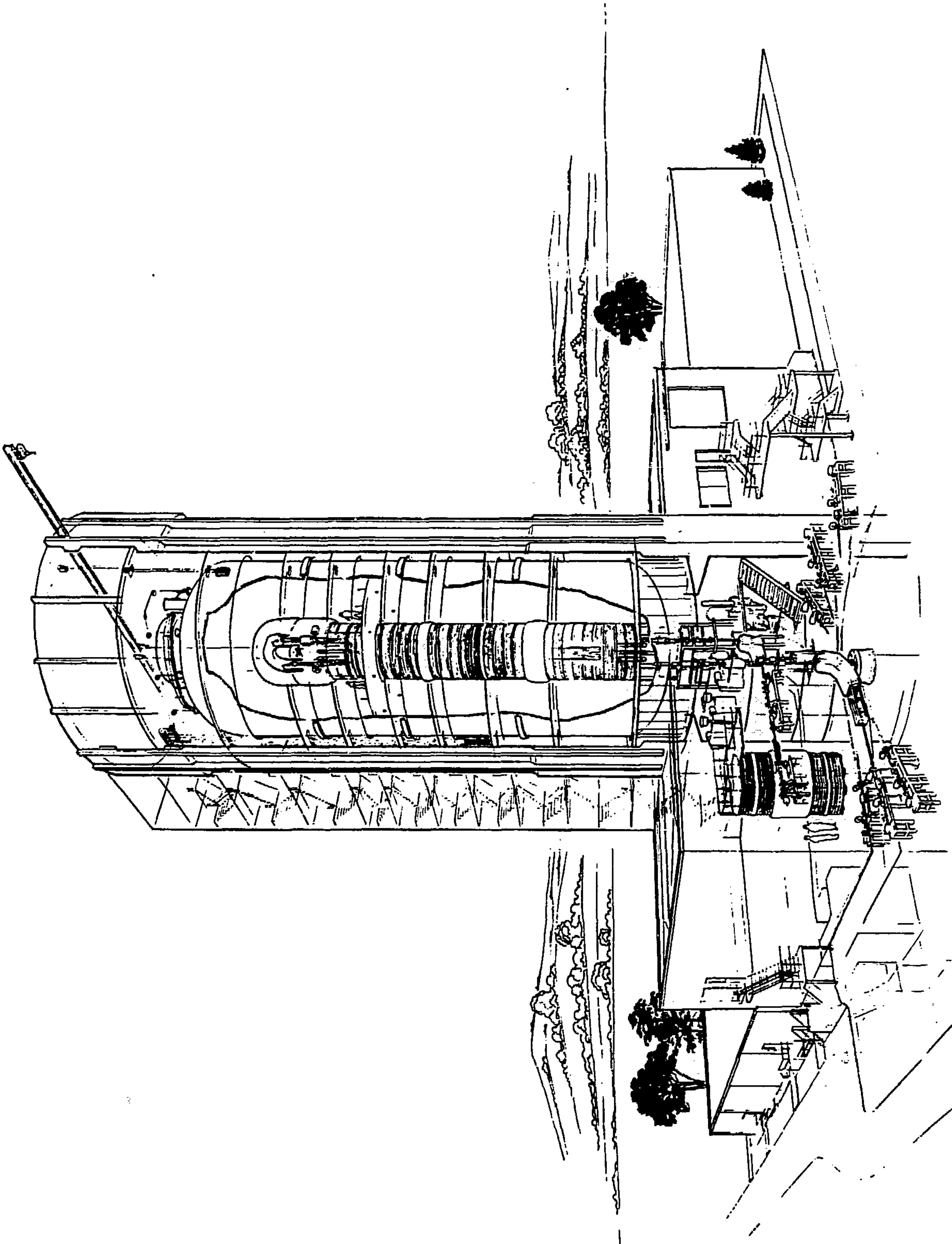
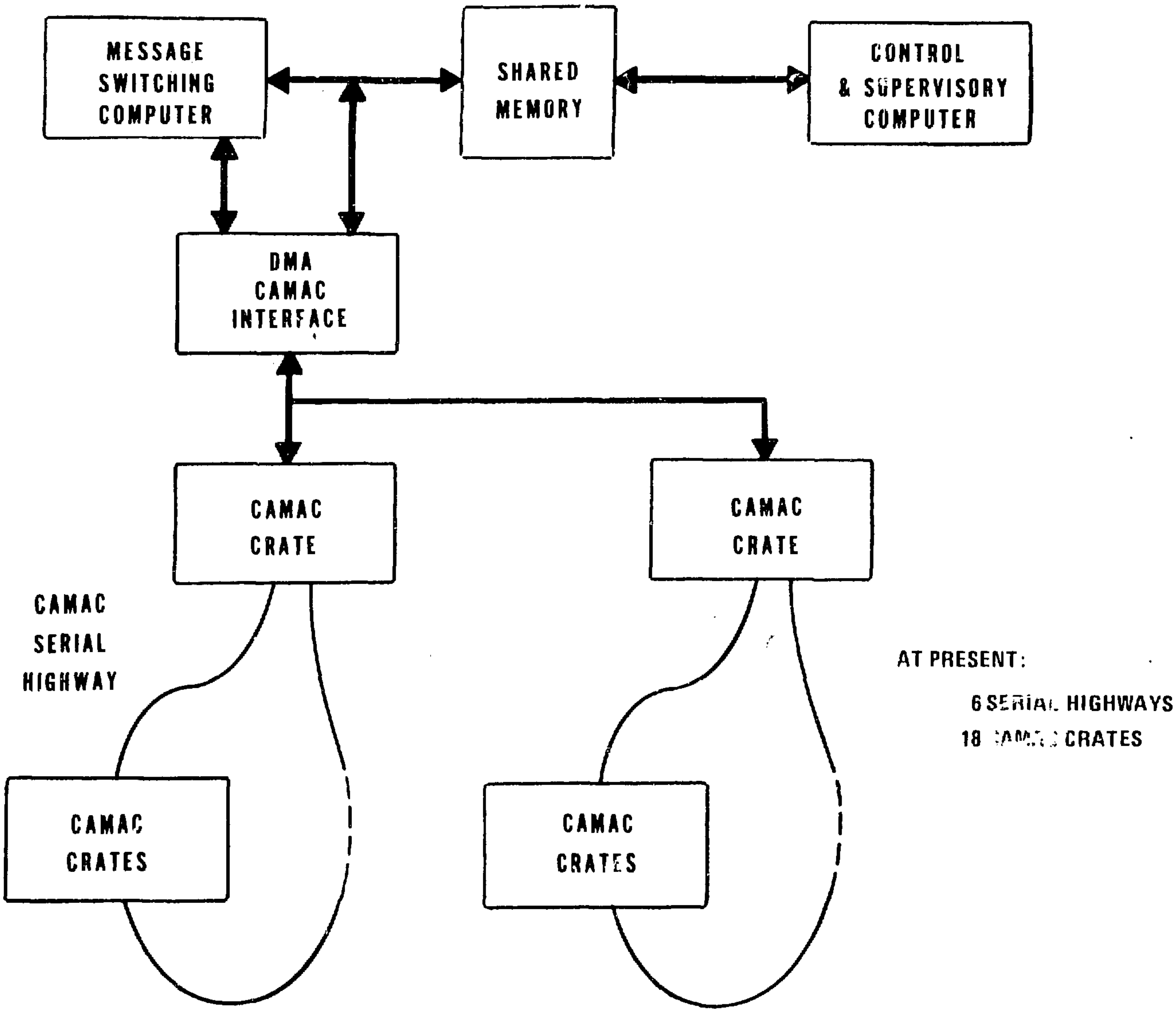
## FIGURE CAPTIONS

Fig. 1. The Oak Ridge tandem accelerator.

Fig. 2. Simplified block diagram of the tandem accelerator control system.

Fig. 3. The tandem accelerator control console.

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SHARED MEMORY
CONTROL & SUPERVISORY COMPUTER
DMA CAMAC INTERFACE
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CAMAC SERIAL HIGHWAY
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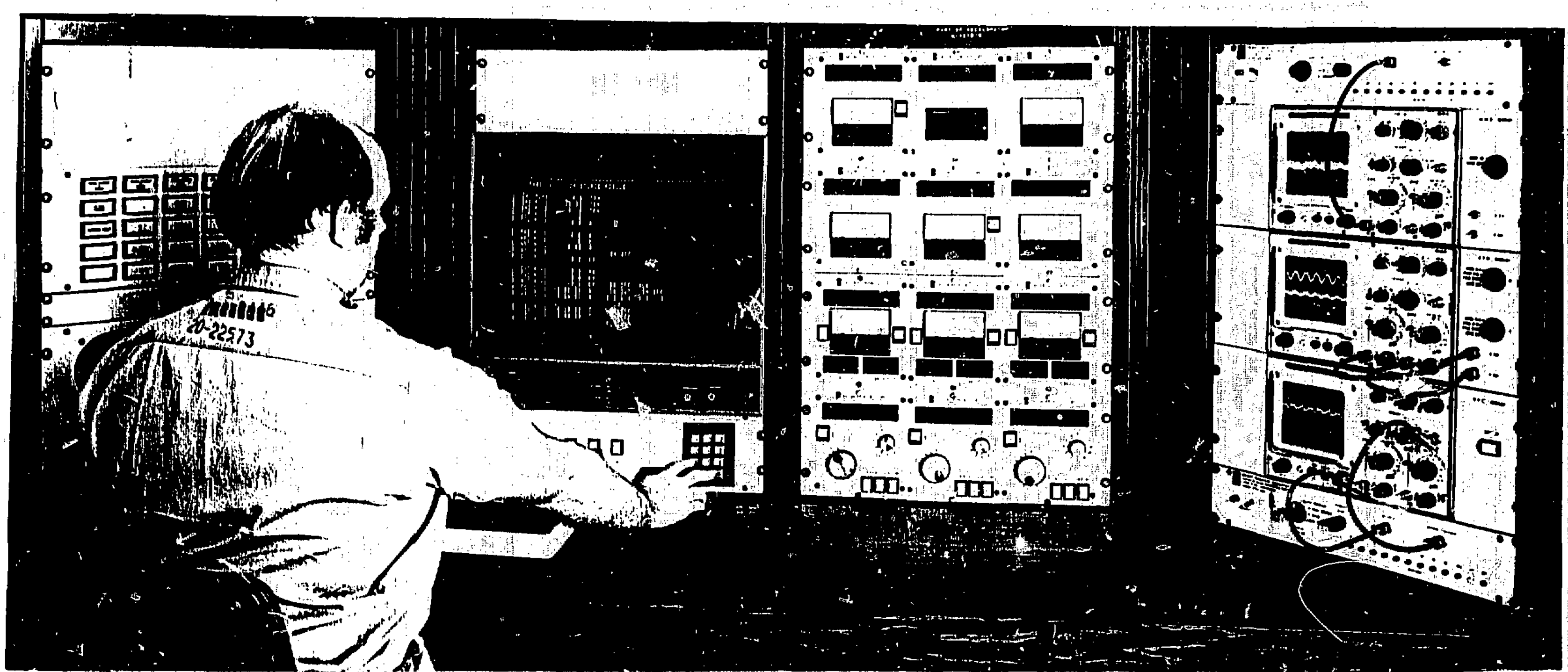
CAMAC CRATES
AT PRESENT:
6 SERIAL HIGHWAYS
18 CRATES

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