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DATA ACQUISITION SERVICES AT PPPL

BY

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DATA ACQUISITION SERVICES AT PPPL*

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ABSTRACT

The current status of DAS-1800, the data acquisition system built around an IBM-1800 computer, is reported; hardware and software developments allowing the concurrent servicing of ST, FM-1, and ATC are described; and details are given of the changes in usage of DAS-1800 during the some three and a half years of its existence. Finally, plans are discussed for providing similar data acquisition services for PLT when it starts operation in less than two years.

Introduction

Some of the goals of the data acquisition system for the major experimental devices at PPPL have been:

- a) to provide on-line, multi-user data acquisition, analysis, display, and archiving;
- b) to give real-time guidance in conducting experimental runs;
- c) to relieve experimenters of arduous data reduction and analysis;
- d) to provide possible greater insight by extensive comparisons and complex calculations;
- e) to make feasible otherwise inconceivable experiments;
- f) to permit concurrent program preparation and on-the-fly changes to the system;
- g) to provide a convenient, high-level language so that the experimenters can do as much of their own programming as desired;
- h) to allow certain analyses in the background without having to transfer voluminous data to the University's Computer Center, and,
- i) to provide interactive analysis and design facilities, which the Computer Center does not.

The original facility was conceived as a medium-sized computer with vendor-supplied and supported foreground/background monitor system, FORTRAN compiler, and utility software for providing a somewhat

modest subset of all these goals. The IBM-1800 was chosen on the basis of price and the availability of hardware maintenance of good repute.

System Expansion

It was realized from the start that some PPPL produced hardware and software would later be necessary to meet the detailed requirements: analog data taking speed, for example. However, with some pre-delivery preparation and experience gained with the similar computer already installed for process control of FM-1 [1] it was possible to have the new facility within about two weeks taking useful data for the Thomson scattering experiment on the ST-Machine.

The expansion in DAS-1800 usage over the past three years has required the addition of hardware from IBM, from other vendors, and from our Instrumentation and Electronics Sections. Besides hardware changes, it has also been necessary to institute major software modifications. Before detailing these evolutionary changes, it should be observed that, especially with the present very heavy usage of the system, there are some problems: the IBM monitor is not completely foolproof, not all the IBM software is thoroughly bug-free, the FORTRAN provided is not a full FORTRAN IV, and there is not enough systems management capability for knowing in detail what the computer is doing so as to be able to reduce interference between experiments. The combination of these weaknesses and the ever increasing utilization of the present system indicates that, when PLT comes on-line in less than two years, it will be necessary to add major new data acquisition facilities for this much more complicated experimental device.

Changes in DAS-1800 Usage

When this data acquisition system first started, only one experimental device was serviced at a time and there were only a limited number of experiments using computer assistance. Now practically any combination of experiments may be running simultaneously on the different machines, each of which has its own repetition rate controlled by separate, uncoordinated timers. Thus, in

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general DAS-1800 cannot know a priori what will be happening. The complex priority system of the IBM-1800 helps sort things out, but contention for the limited resources of the computer is mounting. In addition to the gross increase in DAS-1800 utilization as the physicists are becoming convinced of the efficacy of computer assistance for their experiments, there is a subtle increase in system loading caused by more sophisticated usage of the computer's abilities. The amount of information contained on the scope displays included with this report, as compared with those from earlier ones [2],[3], illustrates this increase in sophistication.

A final observation should be made about the status of the current operation in terms of the hundreds of programs on the system: So many of these were written so long ago by physicists who in some cases are no longer associated with the specific experiment, that now the responsibility for maintenance of almost all programs has fallen to the small DAS-1800 operations and programming staff. In fact, the problems of system integrity alluded to above necessitate a working knowledge on the part of the staff of all programs that run on DAS-1800.

Hardware Expansion

Although the IBM-1800 was a satisfactory choice for the basic central computer for our data acquisition system, it is known to have many shortcomings. Some of the more serious of these are:

- a) the analog-to-digital converter is slow,
- b) there is no means for the simultaneous sampling of several analog signals or for sampling at a timer-controlled rate,
- c) the hardware logic levels are not standard and do not even match within the computer,
- d) there is no standard support for teletypes (only for two special IBM typewriters and up to six additional low-speed, serial printers),
- f) floating-point hardware is not available, and,
- g) by now the computer is no longer in current IBM production, so no significant systems enhancements can be expected.

Our cost-effective solutions to some of these shortcomings follow.

Current System

Fig. 1 is a recent photograph of the

DAS-1800 computer room; Fig. 2 shows the current status of the complete system. If this diagram is compared to a similar one for the status two and a half years ago [3], it will be seen that core memory has been doubled; disk storage expanded by a factor of eight; one typewriter, two serial printers, and a high-speed line printer have been added; analog & digital I/O facilities greatly expanded (especially by the addition of another PDP-8/I high-speed A/D terminal); and new storage scope and hard copy units added.

Memory. The additional core memory was purchased from Computer Hardware, Inc. and, besides being substantially cheaper than that from IBM, it has the added advantage of being somewhat faster. The disk storage expansion was provided by the purchase from a third party of used units at a small fraction of the IBM price. (Maintenance for these units, however, is included under our regular IBM contract.)

Line Printer. The line printer, manufactured by Data Printer, Inc., is again much faster than the standard one offered by IBM: 600 lpm as compared to 240 lpm. Since only minimal interfacing information was supplied by IBM, some two man-months of engineering were required to design the hardware for connecting the line printer to the computer in a manner transparent to the 1800 operating system. However, even including the used PDP-8/I for a buffer-controller, the total cost of the line printer subsystem (Fig. 3) was substantially cheaper than it would have been from IBM.

A/D Conversion. The inherent speed limitation of the 1800 listed in (a) above has been satisfactorily overcome by a Laboratory designed six-channel A/D for a PDP-8/I [4]. A second such unit with greater flexibility and faster simultaneous data taking is now under construction. In addition a Biomatron 1015 Waveform Recorder, which provides up to 100 kHz sampling of four simultaneous channels, has been interfaced to yet another PDP-8/I. (See Fig. 4.) All three of these PDP-8/I's, as well as the one that controls the line printer, have two-way, parallel interfaces to the 1800, which allow a) the 1800 to load programs or data and control the operation of the PDP-8, and b) the PDP-8 to transfer data and control commands at about 50 kHz to the 1800.

Simultaneous Sampling. Fig. 5 shows hardware designed and built by the PPPL Electronics Section for solving the problem mentioned under (b) above. The top unit (which would be located in one of the machine control rooms) synchronizes

simultaneous sampling by the lower sample/hold unit (located in the analog cabinet of the 1800) of up to 16 analog signals at the rate selected by the panel controls or by an external timer, and meters out the held values to the 1800, using the standard ready/sync facilities. If the overall rate chosen is too fast for the 1800 to convert, the warning light comes on. The status of this light and the controls is read by the 1800. By means of the knobs located beneath the BNC connectors on the sample/hold unit individual signals can be associated with any one of four synchronizers.

Signal Conditioning. The incompatibility of logic levels of the 1800 mentioned in (c) above, along with the fact that each of three machine control rooms has a separate ground plane, has required extensive signal conditioning and the use of differential driver-receiver circuitry. In the computer room these are housed in interface racks (Fig. 6), which also contain other Laboratory built hardware, such as active circuits to correct for the writing characteristics of the storage scope displays and interfaces for high-speed parallel digital connections to the PDP-8's and two Northern Scientific pulse-height analysers. Also in these racks are digital output multiplexers for "strobing" digital input information onto the input data bus from thumbwheel switches, "touch-tone" pads, teletype-like keyboards, the digital calendar/clock, and other low-speed digital devices. In each of the control rooms there is additional interfacing circuitry which is common to the experiments on that machine.

Interactive Terminal

Fig. 7 shows the expansion of IBM capabilities with other commercial and PPPL hardware for the interactive data manipulation facilities in the DAS-1800 computer room. In conjunction with the typewriter and the box of function switches, the Graf-pen digitizer can supply data to design and analysis programs for output displays on the storage scope. The Graf-pen itself can be used either with the standard digitizing tablet or directly on the scope face, simulating a conventional light pen.

DAS-1800 Software

DAS-1800 now runs under the IBM-1800 Multiprogramming Executive Operating System (MPX). MPX uses partitioned core and a multilevel-priority queuing system to simulate concurrent execution of several programs. Actually, the central

processing unit executes only one program at a time, but the monitor can suspend a program in one core partition and execute another in a different partition, returning later to complete the first program. Such suspensions of execution occur when a higher priority program interrupts a lower priority one, when a program initiates input/output operations that will not be completed for many machine cycles, or when the program directs its own suspension for a specific time interval as it might, for example, to enable the user to view some display for a few seconds before presenting the next display.

The expansion of the 1800 main memory to its maximum 64k has permitted configuring the IBM Multiprogramming Executive Operating System (MPX) with an in-core monitor of 28,000 words and twelve user partitions, mostly of about 1500 words or so and one of some 20,000 words. This large partition is used for background jobs such as program compilations and extensive data analyses and for larger real-time jobs, the latter causing any background job to be temporarily checkpointed to disk. This ability of a background job to be swapped out of core to make room for real-time jobs has led us to a philosophy of requiring analysis programs running more than a few tens of seconds to be run in the background, i.e., be initiated by reading cards, rather than by pushing buttons or the like.

The size of the different partitions, unfortunately, is changeable only during systems generation, which is far from a trivial process. Thus, since many partitions are assigned to the exclusive use of a particular experiment, much memory can be wasted when that experiment is not running. In general, however, 64k of main memory and some eight million words of disk storage is quite sufficient most of the time for servicing the several concurrent experiments and various background jobs.

Systems Software

Over the past three years the main changes that have been made to the IBM systems software, as well as to our own locally written routines, have been necessitated by concerns for speed and for systems safety. The MPX monitor system is overly general purpose, and the object code generated by the FORTRAN compiler is not especially efficient in terms of core or execution speed. We have been forced often to do special coding in assembly language for widely used subroutines and time-critical parts of programs and even

to make direct modifications to MPX itself, realizing that this latter procedure in some cases may invalidate part of our IBM software support agreement.

As far as system integrity is concerned, the problems have multiplied as the usage of DAS-1800 has become heavier. On a multi-user system it is bad enough when other concurrent use degrades normal response times, but it is intolerable when a mistake in operational procedures or a simple programming error can cause system failure. Since both of these undesirable effects occasionally obtain, much current effort is going into rewriting programs for greater safety and into devising routines for probing the operation of the monitor system.

Memoscope Display Subsystem. The general pattern of computer use on DAS-1800 is a) data acquisition using standard MPX analog input routines, b) data storage on disk also using MPX routines, and finally, c) display of raw data or calculation results on Tektronix storage oscilloscopes ("memoscopes"), with hard copies of the displays available from associated Tektronix hard copy units. The memoscope display system was provided, but not supported, by IBM. Extensive local modifications have been made to these programs both to make programming of elaborate displays easier and to eliminate bugs in the system.

Displays are directed to one of sixteen scope channels in the experimental machine control rooms. Any channel can be monitored from the computer room. The basic display subroutines erase any channel, draw axes, write text, and plot data as a connected line or as a series of points, asterisks, etc. All subroutines are easily callable from FORTRAN programs. Messages and numerical values can be written on the displays using FORTRAN WRITE and FORMAT statements. This has been accomplished by modifying the FORTRAN input/output subroutines that ordinarily control an incremental plotter to pass text to memoscope character generation routines. Memoscope displays are easily programmed, and hard copies from the associated units are legible enough to allow many of the physicists' lecture slides and paper illustrations to be made directly from the hard copies. All the illustrations of computer output data in this paper were prepared in this manner.

Keyboard Subsystem. The IBM methods for calling programs or entering data from outside the computer room are limited. To augment these capabilities, teletype-like keyboards have been connected to a

digital-input data bus, one such keyboard in each control room, with a software system developed to service the keyboards as follows: A core resident program responds to a process interrupt issued by a keyboard, strobes the data onto the bus, stores the character into a core buffer devoted to that keyboard, and echoes the character on a memoscope next to the keyboard. When a RETURN or ESCAPE character is detected, the core resident program queues another program specific to the keyboard and the exit character entered. This program operates on the buffer of characters, making decisions on the basis of key words found in the buffer. Programs queued by the RETURN key display or change the values of core resident variables; programs queued by the ESCAPE key queue other programs. A tree structure of prompting messages is also included in the system. The most basic information on the keyboard subsystem is displayed on the associated memoscope in response to the sequence QUESTION-MARK, RETURN or QUESTION-MARK, ESCAPE. This initial message tells the user how to call up more detailed messages, which may in turn refer him to further messages.

Miscellaneous Changes to MPX. Other local enhancements have been added to the IBM software in order to use the 1800 hardware to the fullest. For instance, each 8k of IBM core memory has associated with it an additional 512 words of so-called "auxiliary core" for use by the IBM maintenance routines. Little of this auxiliary core is ever used for this purpose, the rest remaining virtually inaccessible, since only special assembly language instructions can use it. Although the IBM manuals contain little about the very existence of this extra core, we did learn of its usefulness by word-of-mouth from other 1800 users and are now using this extra "free" core for code conversion tables.

Since there is a general lack of utility routines supplied by IBM with the 1800 computer, it has been necessary to write a set to perform such functions as card duplication and copying files between disk and magnetic tape, paper tape and cards, etc.

Applications Software

The design of the DAS-1800 system is such that the user-physicist should be able to do all the programming necessary to analyze the data taken for him by the customized acquisition routines and to display the results on his memoscope. In practice it is becoming more and more efficient in terms of system resources and experimenter time for the DAS-1800 staff

to write much of the applications software. The following descriptions of experiments are presented in order of increasing physicist participation in programming.

Thermal Conductivity. A study of heat conductivity in FM-1 is now being assisted by the computer. The computer samples the saturation current of a Langmuir probe for a few milliseconds after the application of an electron cyclotron heating pulse to one resonance surface. The probe is moved further into the plasma, and a few seconds later the process is repeated on a newly formed plasma. After fifty such shots the computer plots a three-dimensional graph drawing, as in Fig. 8a, showing current vs. position vs. time. Since the current is proportional to the square root of the electron temperature, the display provides a picture of heat spreading from the resonance surface. In addition, the physicists can call up graphs of individual time slices and superpose graphs of several selected time slices, as in Fig. 8b.

Further computer assistance is employed to investigate the role fluctuations play in heat conduction. The signal from the same probe is split into its dc and ac components and sampled by the computer. After fifty shots the computer calculates and graphs the ratio of the average fluctuation to the average dc signal as a function of time. Fig. 9 shows the multiple raw-data traces and the resulting computed curve.

The software written for this experiment is multi-purpose and has also been applied to a Doppler broadening measurement and to a particle density distribution study.

ATC Plasma Position. The displays of radial plasma position vs. time provided by the computer are especially important to ATC operation, because the radial position is changed during plasma compression. To obtain this information, five pairs of magnetic probes are affixed to ATC along a radius, above and below the plasma, to detect the plasma current. The signals from the upper and lower probes of each pair are combined to eliminate the effects of vertical plasma motion. Analog corrections are applied to the signals before they are fed into the 1800 through the usual analog-to-digital path. A straightforward calculation of the position from the signals proved too time consuming to perform in the ninety seconds between ATC pulses, so the problem was reduced to a table look-up. Each probe signal sample is compared to a

precalculated table of signals and corresponding positions. Since there are five probe pair signals, five position values are determined at each sampling time. The values are then weighted, averaged, and plotted with error bars showing the standard deviation at selected points. Fig. 10 shows the plasma position memoscope and the simplified, one-knob computer control system; Fig. 11 is a typical display for a case in which the plasma was not compressed.

Ion Temperature. Another useful diagnostic tool on ATC is the ion temperature measurement. The flux of energetic charge-exchange neutrals leaving the plasma passes through a helium gas cell in which the neutrals ionize. They then pass through a parallel plate energy analyzer where three photomultiplier tubes detect the flux intensity at three energy values. The 1800 samples the photo-tube currents at an adjustable rate, generally about 1 kHz, and stores fifteen sets of data on disk. By changing the deflection voltage across the plates the energy values to which each photo tube current corresponds is changed. The deflection may be set manually or programmed by the analog output facilities of the 1800. A series of shots are taken at different voltage settings to provide enough points for a least-squares linear fit to a semi-log plot of intensities vs. energy (Fig. 12a) at each point in time. The slope of the line is inversely proportional to the ion temperature. The fifteen temperatures obtained are then plotted vs. time (Fig. 12b).

Magnetic Properties of Instabilities. A request for a computer assisted study of the magnetic properties of plasma instabilities in ATC [5] provided DAS-1800 with its greatest challenge to date. The study requires sampling seven channels of magnetic probe signals at 100 kHz for thirty milliseconds. The 1800 A/D converters cannot operate at 100 kHz, and the volume of data (21,000 samples) made buffering through a minicomputer impractical. The solution was to record the analog signals on a multi-track, variable speed magnetic tape unit. (See Fig. 13.) The tape is replayed later at 1/64 recording speed and digitized at a rate equivalent to 100 kHz in real time.

Although the 1800 has 64k memory, not enough core is available in any one partition to accomplish all the data taking without buffering. Therefore the software had to be written using the table chaining and end-of-table interrupt features provided on the 1800 to write the data to disk as it is digitized. A two-buffer system is used: one buffer of

words is written to disk while the other buffer is filled under data channel control by the analog input facilities. The quantity of data stored on disk from several discharges dictated devoting one million words of disk storage to this experiment.

The seven probes employed in this experiment are situated around the tokamak ring at different poloidal angles; thus the signals may be viewed as a tabulated function in angle and time. Fig. 14 shows the digitized raw data from each of these seven probes. The experimenter is looking for disturbances of the form $\cos(m(\theta - \omega t))$. The analysis program developed allows for choices among several analytical methods: Fourier transforms in θ , in t , or in both, and integration of raw signals, their transforms, and products of the two. As an illustration, Fig. 15 shows the auto-power spectrum from one of the probes. The same analysis is also applied to computer simulated data, which includes distortions expected in the real data. Comparison of the real and simulated data provides new insights into the nature of the phenomena recorded.

The data can be written to magnetic tape and processed on Princeton's IBM 360/91, but at present the short turn-around times and the close interaction available on the 1800 outweigh the far greater computing power of the 360/91.

ST X-Ray Spectra. DAS-1800 processes electron bremsstrahlung data from a Northern Scientific 710 pulse-height analyzer (Fig. 16), which counts pulses from an X-ray detector for about an hour and then transfers 1024 channels of counts to the 1800. In addition, the experimenter enters the various parameters of operation to enable the 1800 to unfold the spectrum. The 1800 converts channels to energy and compensates for the efficiency curve of the detector used and for the absorption by metal foils through which the X rays pass; it takes into account the solid angle of plasma from which the X rays emanate, the time period over which the counts were collected, and the counts lost due to pulse pile-up; and finally, it plots the spectrum of X rays emitted per unit volume per unit time vs. energy. The spectrum can be interpreted as a measure of the electron velocity distribution. Fig. 17 shows a typical spectrum display.

A bremsstrahlung spectrum is also calculated by an integration over the temperature and density profiles obtained by the ST Thomson scattering experimenters. Comparison of the two

spectra indicates the impurity level in the plasma.

Thomson Scattering. Two Thomson scattering experiments are now serviced by DAS-1800, one on ST and one on ATC. (Fig. 18 shows the experimenter station in ATC.) On ATC the beams from two ruby lasers are directed through the plasma where they are Thomson scattered by energetic electrons. The Doppler broadening of the scattered light is recorded by an eight-slit spectrometer. Its photomultiplier tube currents are stored on integrating capacitors for post-shot transmission to the computer. The photomultiplier tubes are gated twice for each laser in use, once just before the laser is fired for a measure of the plasma light and once when the laser is fired. Readings taken with no plasma provide further corrections to the data. The eight values are corrected for plasma light and direct laser light and are then computer fitted to a Gaussian curve and plotted with error bars. (See Fig. 19.) The width at half maximum gives the electron temperature; the total intensity of scattered light is proportional to the electron density.

The temperature and density are recorded on disk along with the radial position of the laser and the relative time at which the lasers were fired. Data from several shots can be plotted to show density and temperature profiles in space or time, as shown in Fig. 20. Further analysis of the profiles combined with additional hand-entered data gives the other plasma parameters, such as energy confinement time and impurity level, displayed below the profile.

The ST Thomson scattering experiment, described in previous papers [3], differs from the ATC experiment in that only one laser is used and the spectrometer has seven channels. The software for the two is essentially the same, since the ATC software was adapted from that for ST.

Heavy Ion Beam. In the heavy ion beam experiment [3],[6] a beam of singly ionized thallium ions sweeps through the plasma where some of the ions are further ionized. The doubly ionized beam thus produced is fed through a momentum analyzer and an energy analyzer to yield signals proportional to electron density, space potential, and vector potential at the point at which the second ionization occurred. These three signals, two error signals, and the sweep signal are fed to a PDP-8/I, which stores the data for post-shot readout to the 1800. The sweep voltage is analyzed to give the radius of the point of second ionization. That information is used to convert the other

signals to functions of radius. Further calculation yields radial profiles of magnetic field and current density, which are plotted on a memoscope. By changing the energy of the beam, the detector line may be moved across the plasma. Electron density or space potential profiles from several shots can be combined into three-dimensional profiles, which are displayed on the memoscope as either contour drawings as in Fig. 21a or as tonal maps as in Fig. 21b.

Interactive Design. When DAS-1800 is not busy gathering or analyzing experimental data, both physicists and engineers can use the interactive graphics facilities of the system with their computer programs for design studies. Representative displays from two of the more significant of these are shown in Fig. 22a (beam probe design for PLT) and Fig. 22b (divertor design for PLT).

Future Data Acquisition at PPPL

Even as the modifications to DAS-1800 hardware and software continue for meeting the present requirements of our current major experimental devices, plans must be made for satisfying the more extensive data requirements of PLT [7]. Despite the fact that ST will be removed to make room for PLT, the ever increasing computer usage of both ATC and FM-1 will have the effect of about maintaining the current level of DAS-1800 utilization; thus, since the main memory of the 1800 cannot be expanded any more or be made to run any faster, new facilities will be required to service PLT properly.

Once again a determination was made on the comparative merits of a medium-sized central computer (this time of the IBM-370/135, PDP-10, Sigma 9 class) vs. a multiplicity of highly configured minicomputers (of the PDP-11, NOVA 840, Modcomp II class). The redundancy and operational independence of the latter approach was deemed to be more than compensated by greater power and versatility of the former. Since the cost for a usable system either way would be about the same, the further advantage of easy expansion as it becomes necessary additionally tipped the balance toward a central computer with only physically small front-end facilities in the actual PLT control room.

Another development which may be a factor in the design of the PLT data system is the analog drum system now being assembled for use with the eight-channel microwave interferometer for ATC [8]. This drum will be able to record up to 100

kHz signals on 50 ms tracks, which may be multiplexed for longer recording times, with a total of 512 tracks being available on a fully expanded system. Data recorded during a machine pulse can be repetitively displayed directly on a normal oscilloscope and later, if desired, be digitized by another PDP-8/I and transferred to the computer. One could imagine a control room set-up in which all analog data from each shot were buffered to such drums and digitized for computer use only on a selective basis.

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Fig. 1. Wide-angle photo of the DAS-1800 computer room.

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Fig. 2. Diagram of complete DAS-1800.

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Fig. 3. Data Printer 600 lpm line printer shown with its PDP-8/I controller beside the IBM-1800 computer.

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Fig. 4. Photograph of Biomation Model 1015 Wave Form Recorder in rack with the PDP-8/I by which it is connected to DAS-1800.

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Fig. 5. Variable-rate synchronizer and sample/hold units for simultaneous multi-signal analog data acquisition.

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Fig. 6. Programmable patch panel and computer room interface racks containing signal conditioning, scope display correction, digital clock/calendar, high-speed digital equipment connection, and low-speed data bus strobing circuitry.

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Fig. 7. Interactive data manipulation facilities, showing typewriter, function switches, digitizer, and storage scope with hard copy unit.

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Fig. 8. Displays from FM-1 thermal conductivity study, showing (a) the Langmuir probe current as a function of position and time, and (b) five selected time slices plotted to a different, reversed position scale.

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Fig. 9. Fifty-shot averaged fluctuation intensity vs. time plot (three-point smoothing shown by '*'s) with multi-trace scope display of ac and dc components of raw signal.

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Fig. 10. ATC plasma position display station with simple, one-knob computer control.

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Fig. 11. Memoscope plot of radial position of ATC plasma with standard-deviation error bars.

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Fig. 12. ATC ion temperature displays, showing (a) least-squares linear fit (for data points between "error bars") on semi-log plot of intensity from three different detectors (plotted *, +, x) vs. energy for a single time slice (with out-of-range values plotted on the abscissa), and (b) temperature (in eV) vs. time plot derived from fifteen such fits.

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Fig. 13. Sangamo Model 4700 analog tape recorder with its associated equipment and computer entry keyboard and memoscope used in the study of magnetic properties of ATC plasma instabilities.

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Fig. 14. Digitized raw-data output (from seven magnetic probes) captured by analog recorder system shown in Fig. 13.

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Fig. 15. Typical display of Fourier analysis of magnetic instabilities from ATC plasma.

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Fig. 16. Photograph of X-ray analysis station in ST control room, showing dual Northern Scientific Model 710 pulse-height analysers, computer interface, parameters entry keyboard, and memoscope.

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Fig. 17. Typical display of an intensity vs. energy spectrum of electron bremsstrahlung X rays from ST machine.

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Fig. 18. ATC Thomson scattering station, showing various equipment for control of the experimental apparatus and for communications with DAS-1800.

SHOT 1254 1.45 JOULES
 POS =250MM DELAY = 90.0MSEC
 TEMP =1255.42+/- 217.3 EV
 DENS = 8.61+/- 0.63 E12 CM-3

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Fig. 19. Corrected output from the seven-slit polychromator of the ST Thomson scattering equipment least-squares fit to a Gaussian, with the resulting temperature and density determinations, other parameters, and identification.

733421

Fig. 20. Electron temperature and density vs. radius from ATC Thomson scattering displayed with other plasma parameters.

5 APR 73
11:23 PM
7275

CF 11.50
OH -12.36
VL 575

VACC 63.9
*** E-7 HE
TIME 120

(a)

734351

(b)

8 JUN 73
3:46 PM
6494

CF 11.52
OH -11.22
VL 0

VACC 63.9
0.0 E-5
TIME 20

D 1861
MAP 16 2

734354

Fig. 21. Examples of different three-dimensional representations of data derived from the ST heavy ion beam experiment, plotted (a) as a profile and (b) as a tonal map.

(a)

24 MAY 73
10:50

START
65.0 CM

STOP
75.0 CM

ANGLE
120.0 DG

E 35
1500.0 KV

XDET
84.6 CM

YDET
13.2 CM

734350

(b)

1.600
1.000
-1.000
1.000
-1.000
1.000
-1.000
1.000
-1.000
1.000
-1.000
1.000
-1.000
1.000
-1.000

734349

Fig. 22. Samples of memoscope displays generated by interactive design programs for (a) PLT heavy ion beam and (b) for PLT divertor.

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