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The Computer Data-Acquisition and Control System for Thomson Scattering Measurements

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THE COMPUTER DATA-ACQUISITION AND CONTROL SYSTEM FOR THOMSON-SCATTERING MEASUREMENTS

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ABSTRACT

The Thomson-Scattering Diagnostic System (SCATPAK II) used to measure the electron temperature and density in the Impurity Study Experiment is interfaced to a Perkin-Elmer 8/32 computer that operates under the OS/32 operating system. The calibration, alignment, and operation of this diagnostic are all under computer control. Data acquired from 106 photomultiplier tubes installed on 15 spectrometers are transmitted to the computer by eighteen 12-channel, analog-to-digital integrators along a CAMAC serial highway. With each laser pulse, 212 channels of data are acquired: 106 channels of signal plus background and 106 channels of background only. Extensive use of CAMAC instrumentation enables large amounts of data to be acquired and control processes to be performed in a time-dependent environment. The Thomson-scattering computer system currently operates in three modes: user interaction and control, data acquisition and transmission, and data analysis. This paper discusses the development and implementation of this system as well as data storage and retrieval.

1. OVERVIEW

The Impurity Study Experiment (ISX-B), a fusion experiment at the Oak Ridge National Laboratory, utilizes several computer systems that interconnect to form the network shown in Fig. 1. Three levels of computers provide the ISX experimentalists with flexible as well as reliable paths from data acquisition and control, performed on the PDP-8s, the PDP-11/34s, and the Perkin-Elmer 8/32, to analysis and storage on the PDP-10. Communication and data transmission are handled by the PDP-11/34s and a PDP-11/45.[1]

The Thomson scattering system is one of several diagnostic devices on ISX for which data acquisition and experimental control are entirely performed by a computer (in this case, the Perkin-Elmer 8/32). The Perkin-Elmer 8/32 is a 32-bit minicomputer operating under OS/32, a multitasking and time-sharing operating system. The system currently has 1 megabyte of core memory, 250 megabytes of on-line storage, and an 800-BPI magnetic tape unit. An RS-232 19.2-kilobaud link connects the 8/32 to the Fusion Energy Division (FED) network, allowing the transmission of data to the PDP-10 for further analysis and storage. Table 1 lists the present configuration of the 8/32.

The Jorway 432 CAMAC[2] branch driver is the CAMAC interface on the 8/32. It presently supports three highways (two serial and one parallel) with a total of 15 crates, six of which belong to Thomson scattering. A powerful software package, PCAM,[3] provided by Perkin-Elmer allows access to CAMAC modules through Fortran or assembler code. Single direct memory access (DMA) transfers as well as block transfers can be handled. Automatic scanning of module addresses

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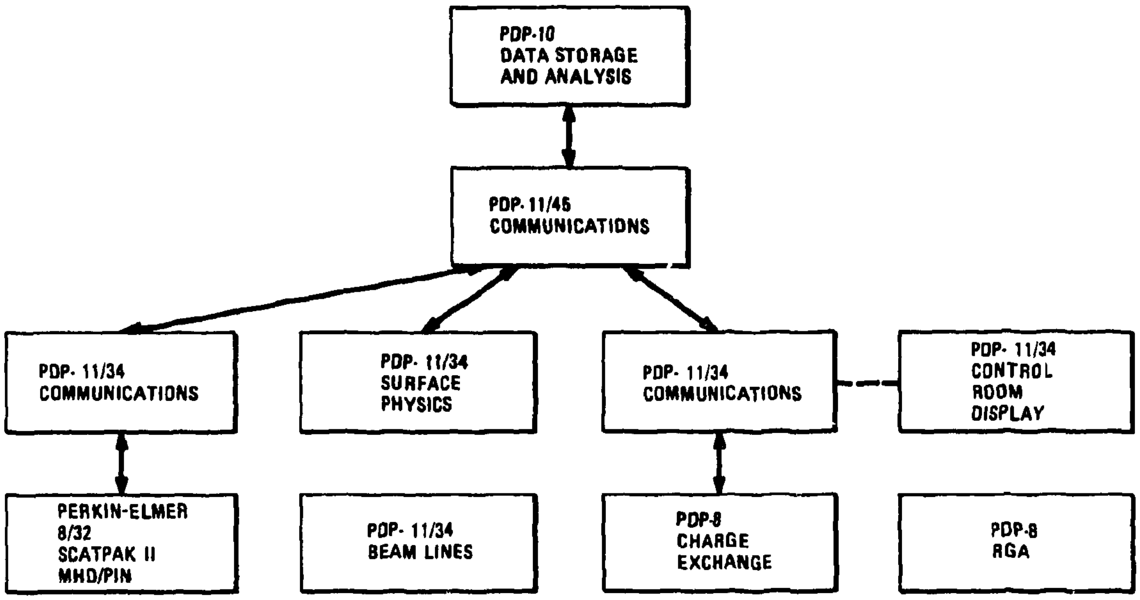

Fig. 1. ISX-B computer network.

Table 1. Perkin-Elmer 8/32 configuration

Single- or double-precision, floating-point processor
1 megabyte of core memory
Writable control storage (2K bytes)
Two 80-megabyte disk units
One 80-megabyte/1.5-megabyte HPT Winchester disk
One 10-megabyte cartridge/fixed media disk
One 800-BPI magnetic tape unit
DMA-CAMAC interface (Jorway 432)
RS-232 communications link (19.2 kilobaud)
Versatec printer/plotter

or subaddresses and full LAM (signal interrupt) handling capabilities are available. OS/32 is capable of initiating a basic DMA transfer every 2.5 ms (Ref. 4). Table 2 lists the eight PCAM Fortran calls available to the 8/32 user.

The Thomson scattering diagnostic, SCATPAK II, obtains two-dimensional (2-D) temperature and density profiles in ISX plasmas by collecting and analyzing laser light scattered from 15 spatial locations along a vertical chord through the plasma. The light source is a pulsed ruby laser. The scattered light from the plasma is focused on the ends of an array of fiber optic bundles that direct the scattered light to 15 polychromators. Here, the light is spectrally distributed and collected by five or seven photomultiplier tubes (PMTs). The signals are then measured by 12-channel analog-to-digital integrators. The optical system is mounted on a translating table that allows the diagnostic to operate at different radial positions within the plasma in order to compile a complete 2-D profile of plasma temperatures and densities. The system outline[5] and a signal flow diagram are shown in Figs. 2 and 3, respectively.

Table 2. PCAM Fortran subroutines

1.	CMCBSC	CAMAC basic subroutine; performs a single DMA data transfer
2.	CMCLW	LAM wait; halts execution until a LAM occurs; suspends task
3.	CMCLP	LAM wait-proceed; interrupts execution when a LAM occurs
4.	CMCESU	CAMAC experiment setup; defines a set of calls to be executed in experiment mode
5.	CMCEWT	Experiment wait; suspends execution prior to an experiment
6.	CMCISU	CAMAC immediate setup; defines a set of calls to be executed at a later time
7.	CMCIGO	Immediate go; submits a previously defined set of calls for execution
8.	CMCSTA	CAMAC status return

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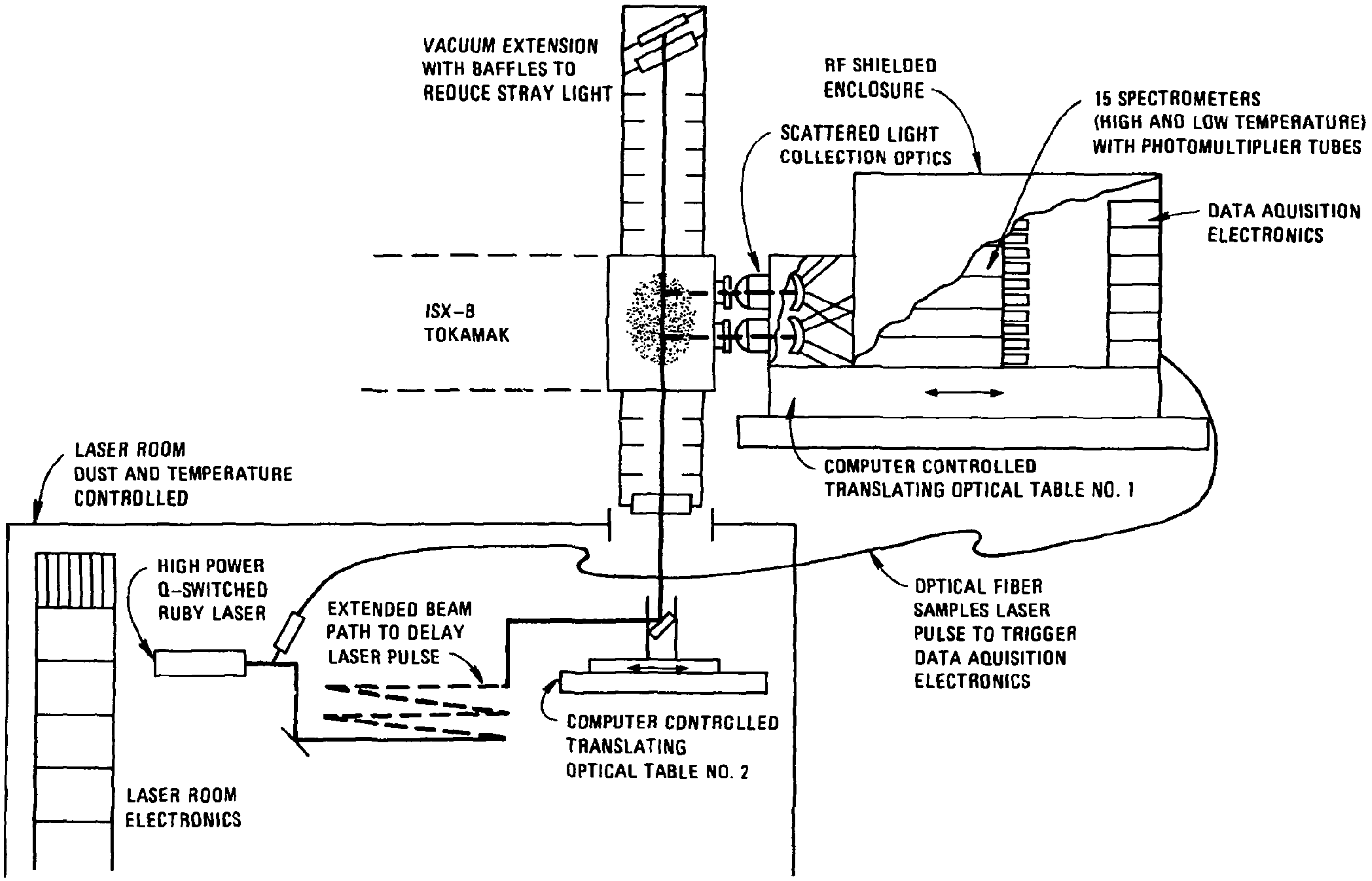

Fig. 2. System outline.

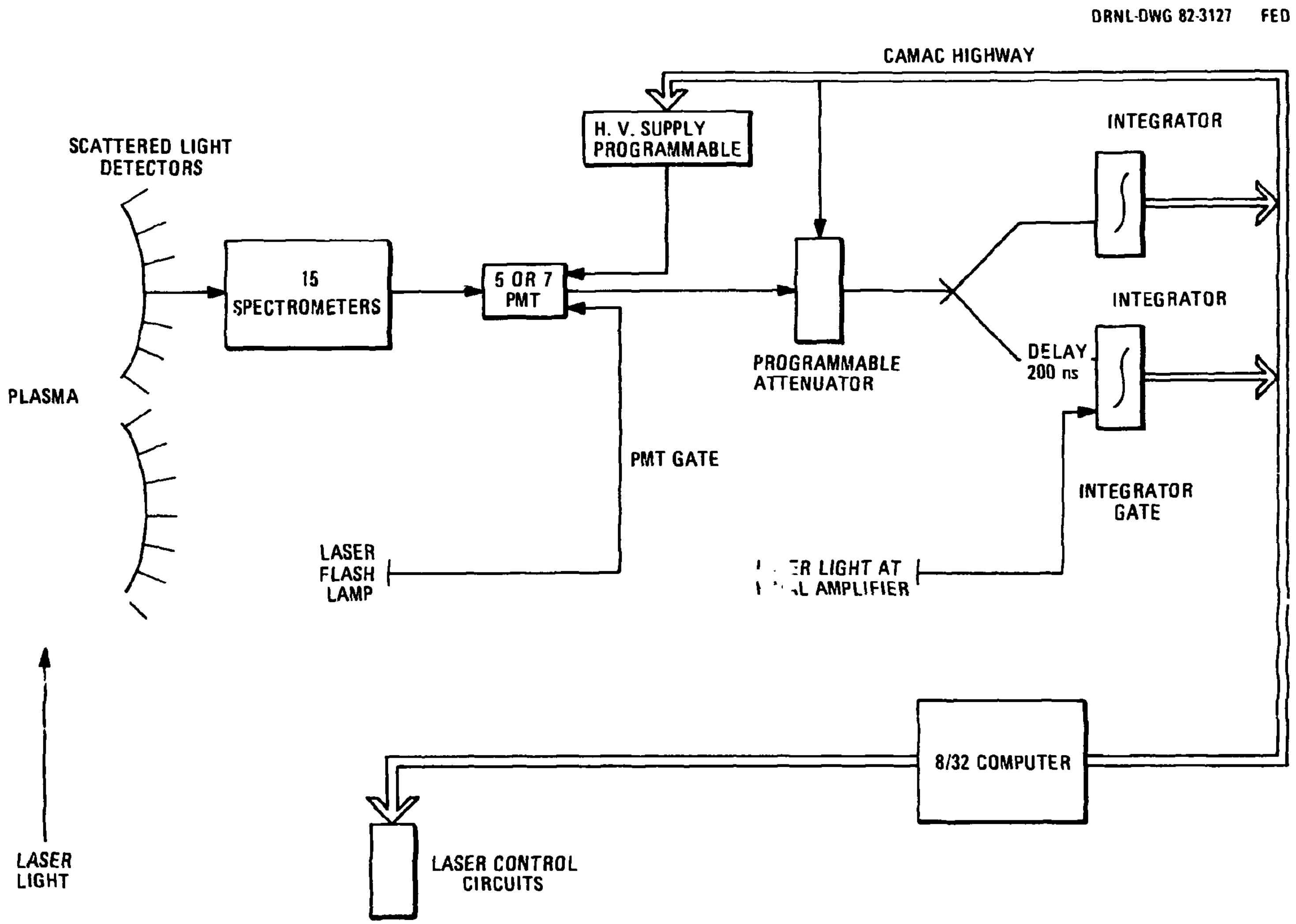

Fig. 3. Signal flow.

2. HARDWARE

The Thomson scattering diagnostic makes extensive use of CAMAC instrumentation for timing, data acquisition, experiment control, and user interaction. The SCATPAK II CAMAC system consists of six Ultima 3000 crates using Kinetic Systems (K.S.) 3952 serial crate controllers. Each crate contains a K.S. 3935 U-port adapter, a K.S. 3924 LAM encoder, and a Jorway 202 display module. Five crates, four located within the experiment enclosure and one in the laser room, one floor beneath the experiment, are linked by a bit serial highway loop of fiber optics. A byte serial highway of ribbon cable supports one crate located in the experiment control room. A diagram of the CAMAC crates and their interconnection is shown in Fig. 4.

The CAMAC instrumentation can be functionally categorized into four groups: data acquisition, translation and alignment, laser diagnostics, and timing. The three data acquisition crates (10, 12, and 14) located in the experiment enclosure are rack-mounted in an electrically shielded room on the Newport Research Corporation (NRC) translating table. Crates 10 and 14 contain nine programmable attenuator modules designed in-house. Crate 12 contains eighteen 12-channel, integrating analog-to-digital converters (Le Croy module 2249W). A high voltage controller (Le Croy Model 2132) is located in crate 10. This module communicates with the Le Croy 4032 high voltage system and can set and read channel voltages as well as turn the supply off and on. Crate 12 contains a calibration module (designed in-house) that controls timing and generates triggers during system calibration. The Joerger dual digital-to-analog converter (model D/A-16) in crate 14

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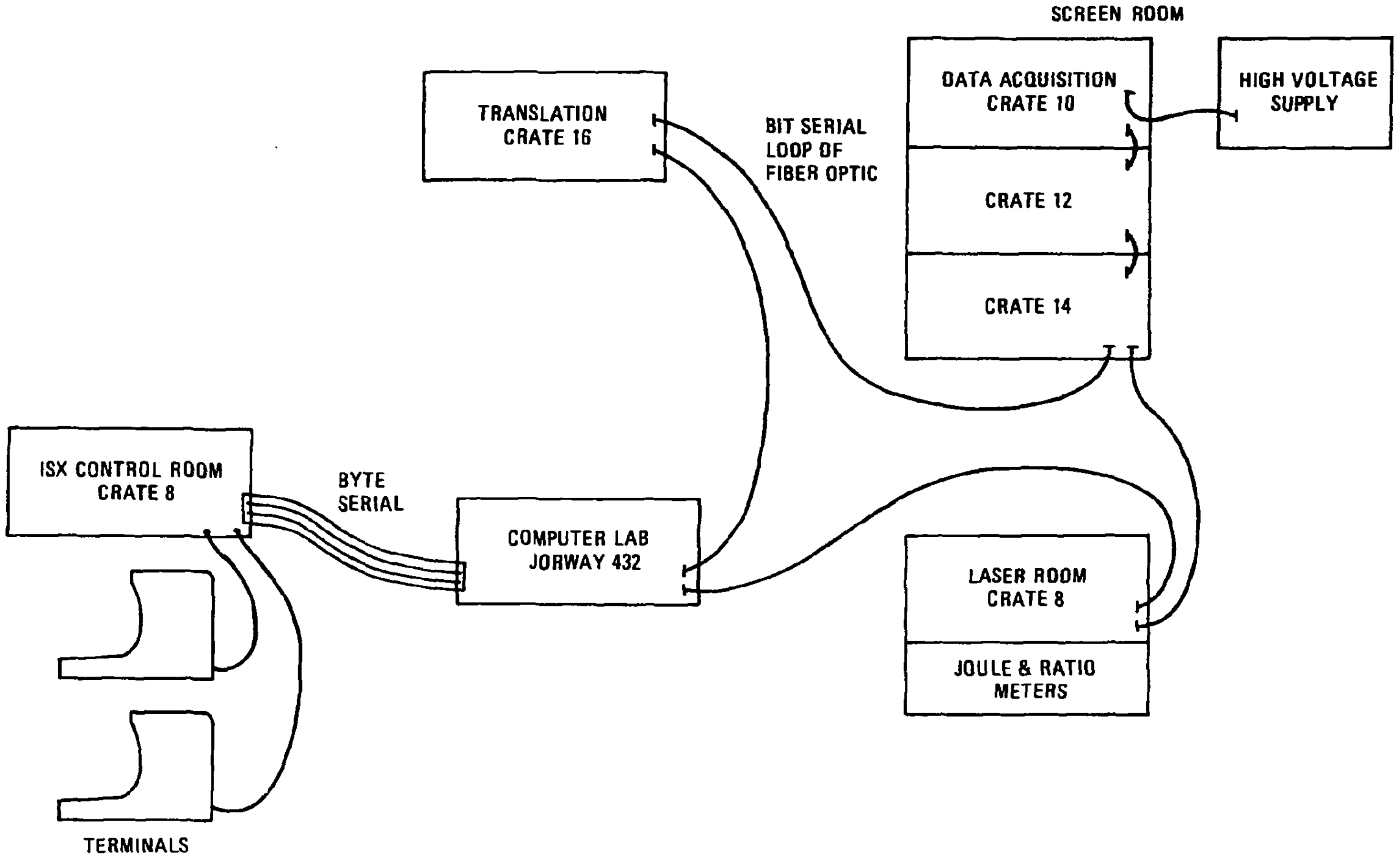

Fig. 4. Thomson scattering CAMAC configuration.

is used to control the power supply voltages for the LED drives during LED calibration.

The translation hardware, contained in crates 8 and 16, enables the Thomson scattering system to acquire data at different radial positions within the plasma. An Anorad translating table, one floor beneath the tokamak, carries a turning mirror that points the laser beam up through the plasma. The NRC translating table in the enclosure carries the optical and data acquisition systems. These tables move by computer-controlled stepper motors. Table positions are monitored by Anorad linear encoders on each table. Crates 8 and 16 contain a Joerger SMC-LCH stepper motor controller for each table and a Joerger S2 up-down scaler to count encoder pulses.

The image alignment hardware is located in crate 16. Fiber optic bundles are mounted on two image surfaces that can be adjusted for alignment of the laser beam. A computer-controlled stepper motor and an absolute encoder are positioned at each end of the surfaces. Each stepper motor is controlled by a Joerger SMC-L controller. The encoders are interfaced to the computer by a 4-channel, 24-bit Joerger QIR module.

The laser diagnostic instruments are a Laser Precision Corporation RJ-7200 ratio meter, which measures the ratio of near-field to far-field laser energy, and a joule meter (designed in-house), which measures the total laser energy. These instruments are interfaced to the computer by a Joerger IR1 module located in crate 8.

The three modules that make up the timing system are the K.S. 3655, a logic isolator (designed in-house), and the Jorway 240 output module. The K.S. 3655 located in crate 10 is an 8-channel timing pulse generator used to generate delays during a laser shot. Tokamak operations signals are interfaced to the computer by the logic isolator module, also located in crate 10. The Jorway 240 output module in crate 10 is used to initiate the laser charge and fire sequence.

Two K.S. 3340 communication modules in crate 10 interface a Tektronix 4006 graphics terminal and a Lear Siegler ADM-3A terminal to the computer. A third 3340 module is used to transmit the shot number from the PDP-11/34 operations computer to the 8/32.

3. SHOT SEQUENCE

A typical ISX shot sequence consists of pre-shot, data acquisition, and post-shot activities. Pre-shot activities are initiated by a pulse at t = −30 s, generated by tokamak operations, which sets a LAM on the CAMAC dataway directing the computer to begin initializing modules. The computer then sends an instruction to the output module to charge and arm the laser. While the laser is charging, integrator pedestals are recorded and stored, the shot number is read from the K.S. 3340, and the pre-shot signal is cleared. At the t = −100 ms signal from operations, the computer initializes the integrator modules and issues a LAM request that will be satisfied when the integrators are gated. When the tokamak discharge is initiated (t = 0), a pulse is generated that starts the preset K.S. 3655 timer. The laser fire sequence begins when the timer times out. During the fire sequence, pulses are sent via fiber optics to gate the PMTs and the integrators and to trigger the joule and ratio meters. The PMT output signal is delayed 200 ns for half of the integrators, so that half of them read scattered light and half read background radiation. The signals from the PMTs are amplified and passed through programmable attenuators to ensure that the signal levels will not saturate the integrators.

Data acquisition begins when the integrator LAM request has been satisfied and consists of acquiring the following data:

(1) 216 channels of integrator signals,

(2) 108 channels of attenuator settings,

(3) 32 channels of PMT voltage,

(4) joule meter reading, and

(5) ratio meter reading.

Post-shot activities include data storage, transfer, and display. The acquired data, along with calibration constants and system information, are written to a disk file and then transmitted to the PDP-10 computer for storage. Each file contains 5024 32-bit words of data and is uniquely named using the tokamak shot number. The net signals and shot information are displayed to aid the experimentalist in system adjustments. Figure 5 shows a typical ISX shot cycle.

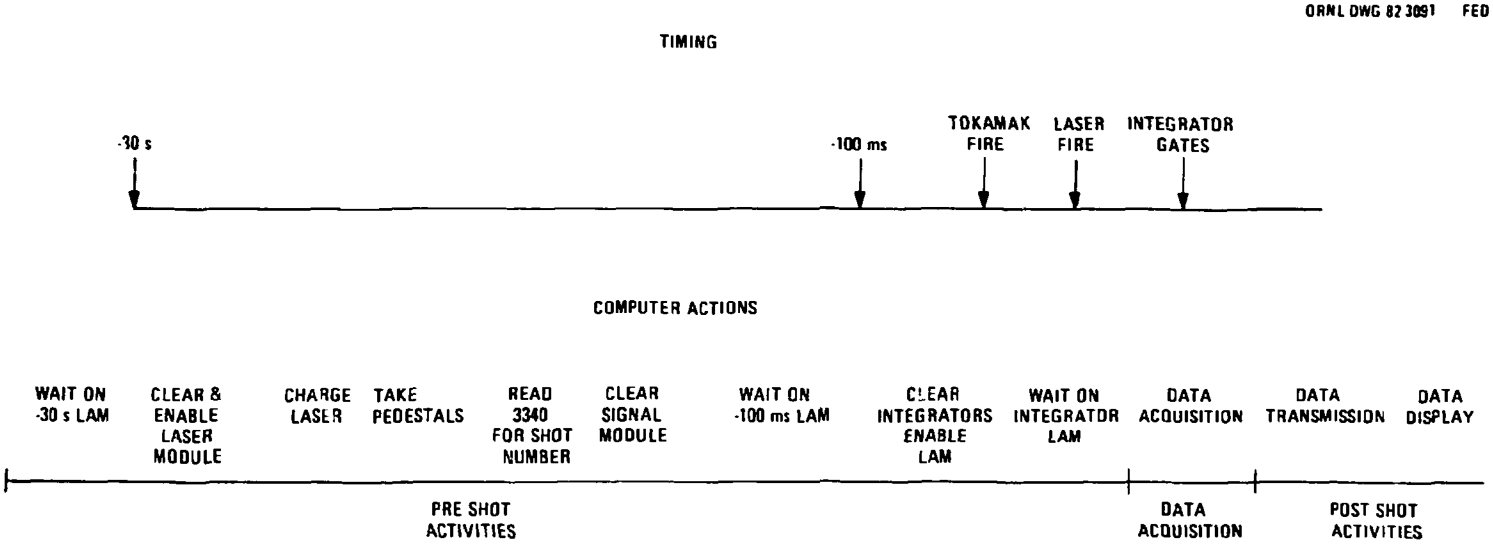

Fig. 5. ISX shot cycle.

4. SOFTWARE

The Thomson scattering operations software operates in three modes: user interaction and control, data acquisition and transmission, and data analysis and display. User interaction and control are achieved through a menu of commands. After each shot, the experimentalist can select any of the following functions:

(1) change attenuator values,

(2) change PMT voltage,

(3) input laser fire time,

(4) move to a new radial position,

(5) change spectrometer positions,

(6) begin a sequence of shots, and

(7) charge laser and prepare for data acquisition.

The data acquisition and transmission mode is entered by selecting the charge laser command. The system cues the operator throughout the data acquisition process, displays any error messages, and announces successful data file transmission.

Figure 6 shows the output from the data analysis and display mode. Attenuator settings, PMT voltages, and net signals are displayed on a Tektronix 4006 terminal. The data are currently analyzed on the PDP-10 computer after the shot file is transmitted.

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```
A         ATTENUATORS
V         VOLTAGES
TA        TABLE     19
TI        TIME    150
P         CHANGE SPECT. POSITION
S         START SEQUENCE
E         END SEQUENCE
C         CHARGE AGAIN

SPECT#      1        2        3        4        5        6        7
STATION    35       26       29       33       34       31       30
RADPOS   298 50    25 00   111.60   233.20   265 40   171 30   141 20

SPECT#      8        9       10       11       12       13       14
STATION    27       28       25       24       32        0        0
RADPOS    53.60    82.40    -3 40   -31 80   201 90     0 00     0.00

SPECT#     15          ALIGN    TUBES
STATION     0          0        0        0        0
RADPOS    0.00       0 00     0 00     0 00     0 00
>
                                               7/26/82     14:2


              ATTENUATORS                          VOLTAGES
CHANNEL    1       2       3       4       5       6       7     H V.   H.V.

   1      1 00    1 00    1 00    1 00    1 00                   2275   2150
   2      1 00    1 00    2 00    1 00    1 00                   2301   2200
   3      1.00    1 00    1 00    1 00    1 00                   2300   2175
   4      1 00    1.00    1 00    1 00    1 00                   2400   2150
   5      1 00    1 00    1 00    1 00    1 00                   2325   2200
   6      1 00    3 16    1 00    1 00    1 00    1 00    1.00   2500   2300
   7      1 00    1 00    1 00    1.00    1 00    1 00    1.00   2300   2200
   8      1 00    2 00    1 00    1 00    1 00    1.00    1.00   2350   2301
   9      1 00    1 00    1 00    2 00    1 00    1 00    1.00   2350   2250
  10      2 00    1.00    1 00    1 00    1 00    1 00    1 00   2400   2250
  11      1 00    1 00    1 00    1.00    1 00    1.00    1 00   2375   2250
  12      1 00    1 00    1 00    1 00    1 00    1 00    1 00   2400   2350
  13      1 00    1 00    1 00    1 00    1.00    1 00    1 00   2375   2300
  14      1.00    1.00    1 00    1 00    1 00    1.00    1 00   2300   2301
  15      1 00    1 00    1 00    1.00    1 00                   2300   2300
 SPECTROMETEP NUMBER?  0 TO CHANGE ALL
>

SHOT 45345                                                             7/26/82
TIME   150 RAD     19 SEQ #                                           16:22:29
SPECT                   SIGNAL                                 BKG
NO. 1     2     3     4     5     6     7     1     2     3     4     5     6     7
 1  15    47    90     9     3                  1    20    12.    2.   -1.
 2 654.  407  1083   435   358                 44    34.   46    16.   41.
 3 596.  567   683   116   135                 12.   45    38    -1.   27.
 4  32.  144    59    19.   41                  3.   94.   44     7.   21.
 5  46     6    11     3.    9                  5.    8.    5     0.    0.
 6 538  1426   459   185   139    40    22     31   379.   48    25.   25.   25.    9.
 7 326.  269.  203   408   126    43    17      7    36    20    32.   13.   11.   19.
 8 764  1201   469   489.  294   286   129     37   188    37.   15.   21.   23.   70.
 9 482   500   871  1173   443   112    90     14    72.   30.   50.   57.   29.   45.
101185   308   942.  634   193   110.   69     46    36    42.   50.   23.   25.   37.
11 725.  922   553   482   393   172    68      8.   72.   26.   24.   53.   31.   14.
12 176.   83   267   164.   51    32    39     10.   49.   23.   18.   22.   30.   49.
13  -1.    0     0.    0     0     0.    1.    -1     0.    0.    0.    0.    0.    0.
14   1     0     0.    0     0     0.    0.     0     0.    0.    0.    0.    0.    0.
15   0     1     0     0     0                  1.    0     1     0.    1.
16 SIG    58    58    54    57    63    53.   62    47
   BKG    15     9     6.    4     6     6     1    56.
JOULES 0.307E+01   RATIO 0 877E+00
C TO CHARGE LASER OR (RETURN)  FOR MENU
>
```

Fig. 6. Operations display.

The Thomson scattering software is based on 15 data files containing spectrometer characteristics and on a system status file containing CAMAC information and other system parameters. This information is read in and stored in a common area. At the present time, three software libraries are used. These collections of subroutines allow the user to read and write data files, acquire integrator data, change attenuators, take baseline pedestals, manipulate the high voltage power supply, and operate the image surface alignment system. These basic routines are used extensively in the higher level calibration and operation programs. A block diagram of the software flow is shown in Fig. 7.

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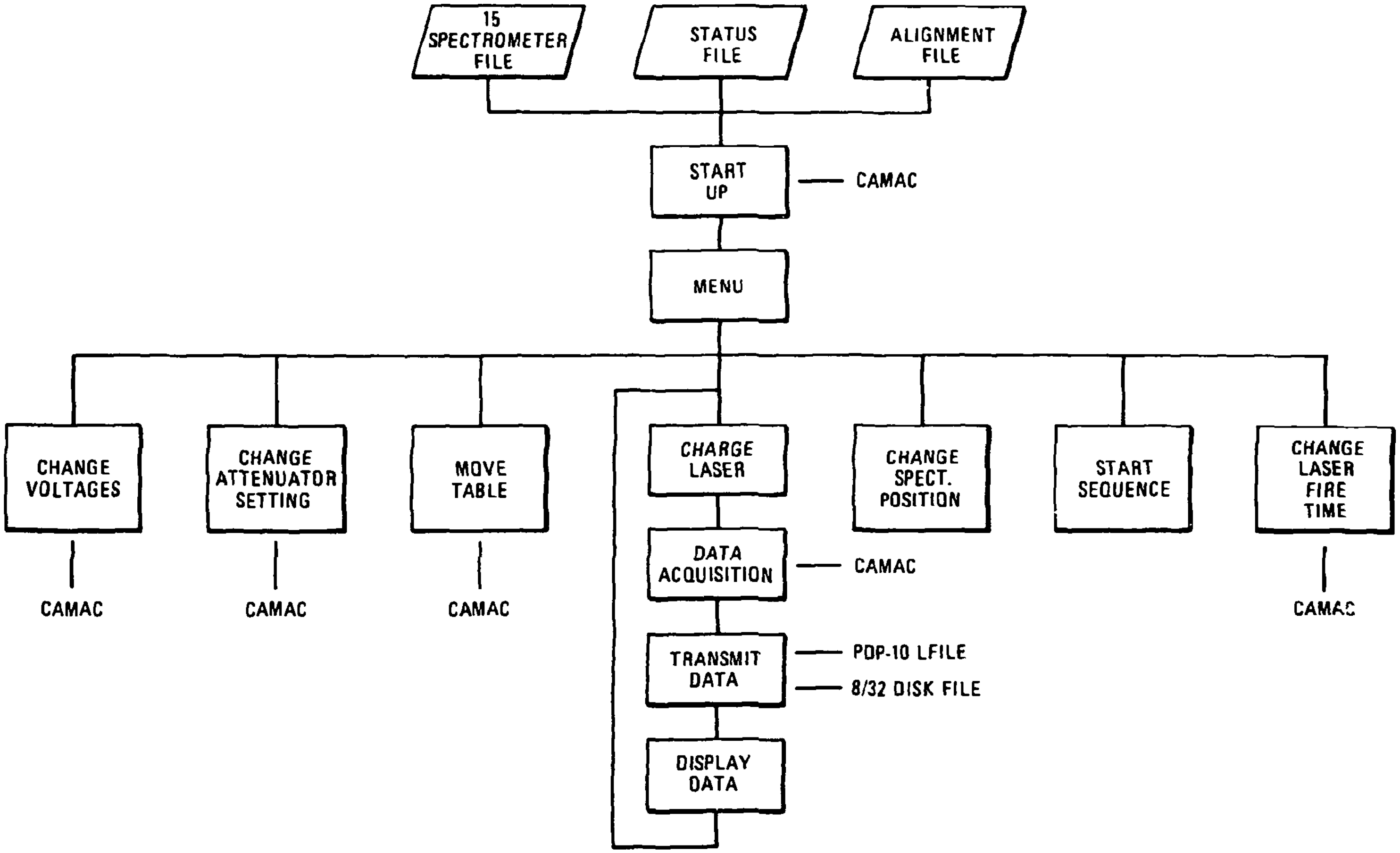

Fig. 7. Thomson scattering software.

5. ALIGNMENT

The computer-controlled procedures used to align the Thomson scattering system are the translation system alignment and the image surface alignment.

The translation system alignment requires aligning the two translating tables, monitoring their alignment while moving to different positions within the plasma, and realigning whenever necessary. These activities are time-dependent in that they must be completed between shots. They are accomplished as follows. As Fig. 8 shows, the home positions of the two tables are at opposite ends of the plasma center. Each time the tables pass through home, the counting register in the up-down counter module is set to the distance, in encoder counts, from the home position to the tokamak center. This enables both encoder registers to read the same whenever the tables are correctly aligned. After every shot, the encoder registers are read; the computer calculates the distance needed to move the tables for correct alignment and moves the tables accordingly. To move the tables during a laser sequence, the experimentalist simply issues the table command and inputs the distance to be moved in centimeters.

The image surface alignment compensates for drifts in the laser beam position. The two image surfaces that carry the fiber optic bundles can be moved from side to side by two stepper motors, one at each end of the surfaces. Figure 9 shows the image surfaces.[6] Two fiber optic detectors, one at each end of the surfaces, are used to detect the position of the laser beam. The signal from each detector is integrated and read by the computer during data acquisition. This information is used to calculate the offset of the laser beam from the center of the fiber optic bundles and to move the surface to correct the alignment. Although the alignment hardware is in place, this procedure has not yet been implemented. The laser system is apparently stable enough that weekly manual alignment is adequate.

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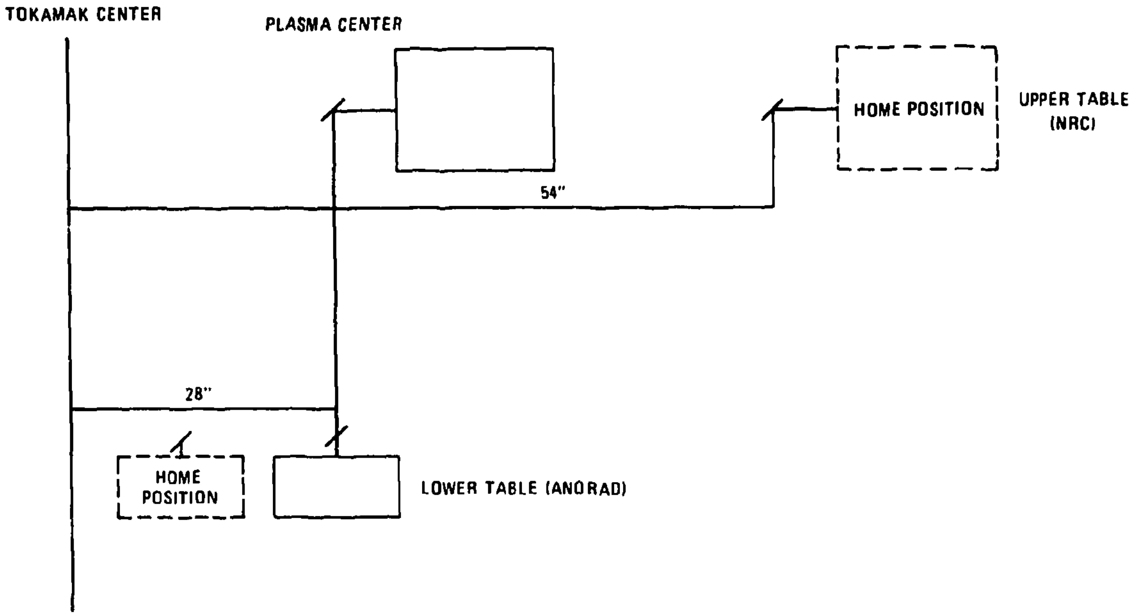

Fig. 8. Translation system.

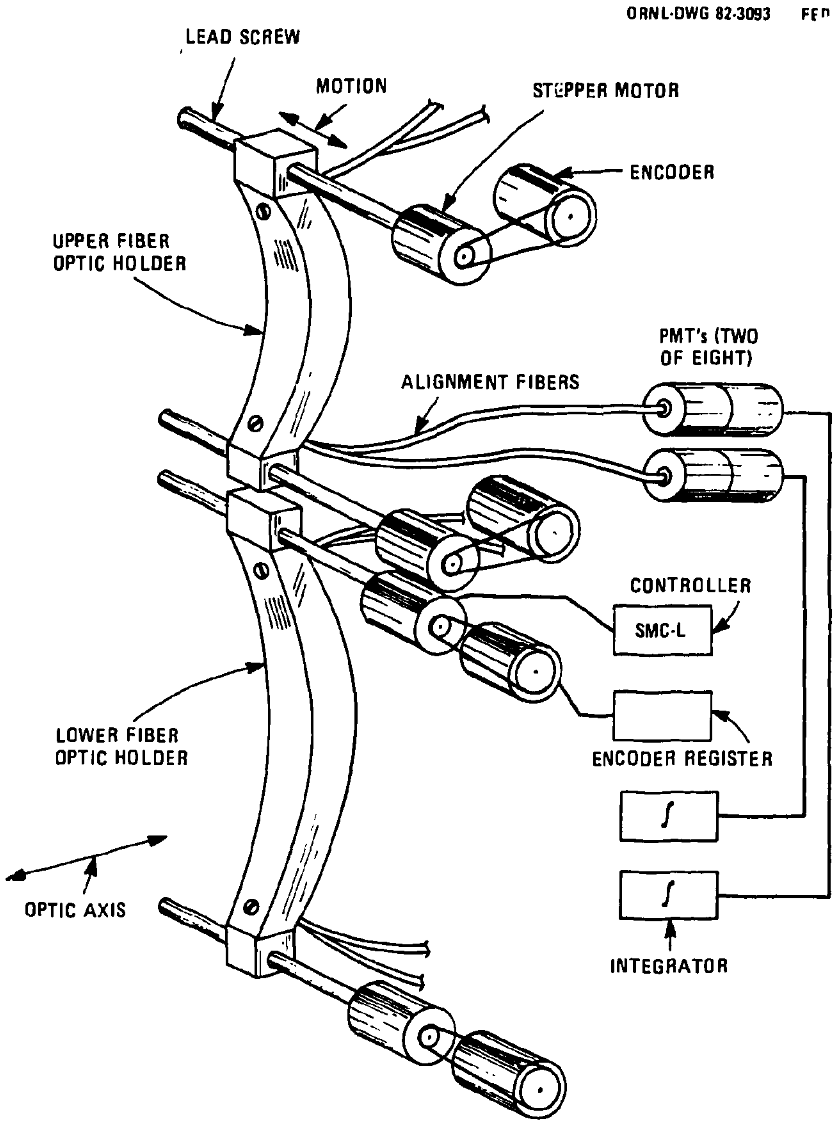

Fig. 9. Image surface alignment.

6. SUMMARY

The data acquisition and experiment control system for the Thomson scattering diagnostic provides the ISX-B experimentalists with reliable data in a real-time environment. Extensive use of CAMAC instrumentation along with powerful CAMAC control software provides the user with a flexible as well as easy-to-use hardware interface. In addition to data acquisition and experiment control, the Thomson scattering computer system allows the user to monitor the systems performance on a shot-by-shot basis. System adjustments can be made during operations if necessary.

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