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DATA ACQUISITION AND PROCESSING ON ELECTRON BEAM FUSION ACCELERATORS*

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Abstract

This report is a review of the hardware and software components of the custom data acquisition facility developed for the Sandia electron beam fusion research program. The facility contains a Modcomp II minicomputer system, Tektronix transient digitizers, conventional oscilloscopes, and an image digitizer. Commercial equipment is utilized as much as possible. Special interfaces were designed for the transient and image digitizers. Careful cable shielding techniques are used to overcome the severe noise environments. The Modcomp multi-task operating system allows two simultaneous users. Special applications programs have been developed for data acquisition and reduction. The facility is currently operational, and a duplicate of this system will be built to support the next generation accelerator EBFA (Electron Beam Fusion Accelerator).

Introduction

This paper describes a special data acquisition and processing facility developed for the Sandia electron beam fusion research accelerators Hydra, Proto I and Proto II. Like the accelerators, the data acquisition facility is a prototype for a future system to support the next generation machine, the EBFA. Many of the diagnostic signals from these machines must be digitally processed for meaningful evaluation. The main objective in designing the facility was to get this processed data back to users within minutes after each shot. This rapid turnaround is necessary to enable proper adjustment of experimental parameters for the next shot.

Accelerators

The Hydra accelerator generates a nominal 1 MV, 500 kA beam with a 80 ns FWHM pulse length.[1] The energy may be routed to either of two separate diode experiment chambers. Proto I produces two simultaneous beams; each is nominally 2.0 MV and 250 kA with a 25 ns FWHM pulse length.[2] The beams impinge on opposite sides of an equatorially mounted anode in the experimental chamber. Proto II also generates two simultaneous beams; each can be as high as 1.5 MV and 2.7 MA.[3] Pulse width can be varied from 25-80 ns FWHM. The beam geometry is similar to Proto I. The accelerators are used for three types of experiments: (1) pulsed power techniques development, (2) diode physics and beam pinching studies, (3) beam-target interaction studies.[4]

The signals most commonly monitored are voltages and currents from the diode and pulse-forming regions of the accelerators. In many cases it is more convenient and desirable to measure dv/dt and di/dt waveforms. Other signals frequently monitored are from X-ray, VUV, and visible radiation detectors and scintillator-photomultiplier neutron detectors.

Cabling System

The accelerators can produce voltage and current risetimes of 10^{14} volts and amps per second. This creates an extremely noisy environment through which signals must be transmitted. Careful shielding and grounding techniques are used to reduce noise pickup to tolerable levels. The high quality coaxial cables RG 214 and RG 331 are used in all runs. All cables are run in a triaxial configuration in either thick-walled rigid conduit or flexible tubing. Rf-tight junction boxes are used to interface between different runs. Feedthru plates are used inside each box to bleed shield noise currents to ground. The triaxial shield configuration is always maintained where cables enter a junction box. A peak-to-peak noise level of 20 mV has been measured from cables located in the noisiest region of Proto II. All the electronic equipment is housed in a high-quality double-shielded enclosure. A diagram of the accelerator and data acquisition facility layout and cabling system is shown in Fig. 1.

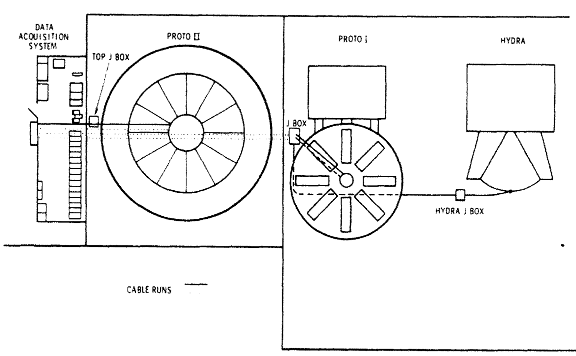

FIGURE 1

Accelerator and data acquisition facility layout and cabling system.

Data Acquisition System Hardware

A block diagram of the data acquisition facility hardware is shown in Fig. 2. The

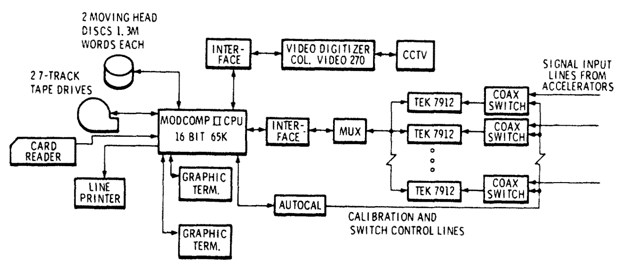

FIGURE 2

Data acquisition facility hardware.

CPU is a Modular Computer System Modcomp II/25 with 65k words of 16 bit core memory. It also contains a hardware floating point processor. This computer was chosen mainly because it was available surplus within Sandia. However, several people on the project had experience in designing special hardware interfaces and writing software I/O handlers for the Modcomp. The Tektronix WP 2000 System was rejected because it could not meet all the hardware and

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software requirements without extensive modifications. The Modcomp CPU and operating system have proven both adequate and reliable.

The computer system contains two moving head cartridge disc drives. Each has a capacity of 1.3 M words. One disc is used primarily for program storage. It contains the operating system, load modules, subroutine libraries, source programs, checkpointing areas, and spooling partitions. The second disc is used primarily for storing shot data sets and directories for each machine. It also contains digitizer calibration curves and cable compensation filter impulse responses. The rest of this disc is divided into scratch pad memories.

Approximately 3000 shots total have been monitored from the three accelerators. A shot may contain as many as 70k words of data. This great volume of data precludes using discs for archive data base storage. Two 7-track, 45 ips, 800 bpi tape drives are used for archiving shot data sets. The 7-track drives were originally selected to be compatible with the drives at Sandia's CDC 6600/7600 Scientific Computing Facility. An extensive library of special subroutines has been developed to read, write and maintain archive tapes.

All data signals are presented to users in graphic form on two Tektronix 4010 Computer Display Terminals. Hard copies are available from Tektronix 4610 and 4631 copiers. Both terminals run at 9600 baud. All plot software for the 4010 terminals was specially written for this facility. The entire graphic subroutine package consisting of low, medium, and high-level subroutines is written in Fortran and occupies about 4k of memory. This plotting package provides for a highly flexible selection of grid sizes and locations, plot modes, axis labeling, and cursor control.[5]

Waveform Digitizers

Most signals to be digitized are acquired on-line via Tektronix 7912 Transient Digitizers. This is the only device capable of the subnanosecond sampling rate required to adequately digitize the fast signals from the accelerators. The facility currently contains 29 digitizers. Each 7912 can be used by all three accelerators. The input signal sources to the digitizers are automatically selected by computer controlled 50 Ω coaxial rotary switches. These switches are contained in Tektronix SM-2 Signal Switching matrices.

The 7912-computer interface controller was designed by the Computer Communications and Interface Division at Sandia. The interface is divided into two parts: a Modcomp 4801 General Purpose controller card in a computer rack, and a multiplexer unit in the 7912 racks. This interface is compatible with the Tektronix CP Bus System. The 4801 provides logic circuits for primary and secondary signal generation, mode control, timing and interrupts. It also contains the 7912 address, command, data and status registers. The timing logic was designed to account for some malfunctions which can occur in the CP Bus interrupt circuitry.

The 4801 is connected to the multiplexer by a single cable which carries 16 data lines, 5 address lines and various control lines. The multiplexer routes the 16 data lines and the control lines to one of 4 possible 7912 bus lines depending on the digitizer addressed. Up to 8 7912's may be connected on a single bus yielding a total capacity of 32 units. The multiplexer also contains interrupt arbitration logic.

Data words are read from the 7912 internal memory at a rate of about 18 μsec per word. Although the digitizer memory can be interrogated every 1.5 μsec, the ASCII knobs data can only be read at the slower rate. A data trace typically contains about 1550 words, and thus can be read out in about 30 msec. This has proven acceptable. The controller supports register, interrupt, and Direct Memory Processor (DMP) I/O. The DMP mode is used exclusively.

The I/O handler for the 7912 system was written by the Minicomputer Software Systems Division at Sandia. The handler operates as a symbiont task in a MAX III operating system. The sympiont is called via standard MAX III I/O resident services, i.e., READ, WRITE REWIND, etc. Individual digitizers are selected by placing the proper unit number in a dedicated User File Table word. The only command which can be broadcast to all units is Master Clear. The specific functions supported by the handler and the associated request are described below:

CALL	FUNCTION
READ	Read digitizer memory
WRITE	Output command to digitizer
REWIND	Digitize next trace
WEOF	Wait until at least 1 7912 triggers
HOME	Master Clear all 7912's.

Autocal

The 7912's analog input may also be connected to an automatic calibration system (AUTOCAL) via the coaxial switches. A block diagram of this subsystem is shown in Fig. 3.

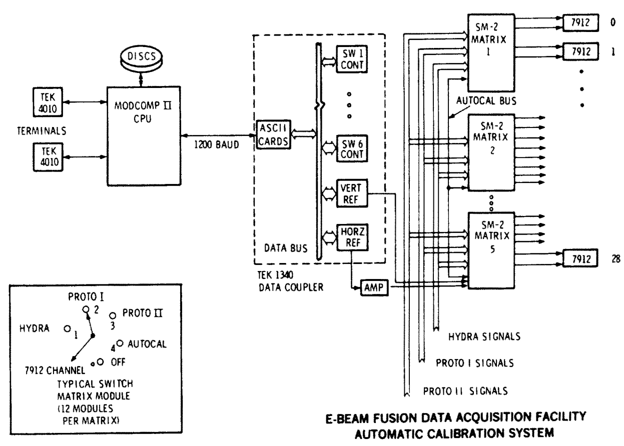

FIGURE 3

Automatic calibration system.

The AUTOCAL circuitry is housed in a Tektronix 1340 Data Coupler. It communicates with the computer via a serial ASCII RS-232 link operating at 1200 baud. The 1340 was originally set up to run at 100 baud, but this proved to be too slow. The Data Coupler contains controller cards for each SM-2 switch matrix, a vertical reference signal card, and a horizontal reference signal card. Vertical deflection factors and time base sweep curves are stored on disc for several knob settings for each 7912. These factors are then used to calibrate signal data read from each digitizer.

Video Digitizer

Some data signals from experiments are acquired off-line in photographic form. Usually they are polaroid prints of conventional oscilloscope traces. Others are transparency images of beam pinches or imploding targets. A Colorado Video 270 Video Digitizer and a closed circuit television system have been incorporated into the facility to digitize this data. A block diagram of this subsystem is shown in Fig. 4. The computer con-

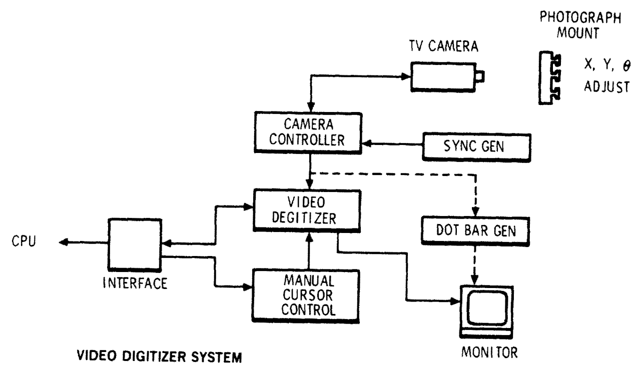

FIGURE 4

Image digitizing system.

troller for the 270 is fairly simple. It contains address, status and data registers and a few control lines. Register, interrupt, and DMP I/O are all supported. The interface address registers are actually counters. They are wired to automatically increment the 270 cursor position after each data word is read or written. The controller circuitry is mounted on a Modcomp 4801 General Purpose Controller Card.

The Manual Cursor positioning unit was designed at Sandia to facilitate alignment and positioning of photographs. It provides for either manual or computer controlled movement of the Video Digitizer X and Y cursors. Cursor positions are displayed on LED readouts in both computer and manual mode.

The I/O handler operates as a symbiont task in the MAX III executive. It is accessed by standard I/O calls i.e., READ, WRITE, REWIND, etc. The handler supports two modes of digitizing: image pixel intensity or threshold crossing location. Image intensity mode is used for digitizing transparencies. Threshold location mode is used for digitizing oscillograms. The raw data produced in this mode is identical to that generated by the 7912's. Thus, the same software can be used to reduce the raw data. The user has the ability to suppress low level noise in the photograph by setting the threshold crossing intensity level.

Software

The e-beam data handling software consists of several "canned" programs available to users. Generally the experimenters on the different accelerators operate the system during their own shots. For this reason, all programs have been made as versatile and yet easy to use as possible. These programs all run interactively on either terminal. Initially the computer could only handle one user at a time. But the increased load as more machines came on line forced us to increase this number to 2. MAX III does not have provisions for operator communications from more than one terminal. Therefore, a small control task was written to allow operators to load and run applications programs from either terminal. This control task is directly connected to two different external interrupt levels. The user can activate the task manually by pressing a button above either terminal. He then types in which applications program he wants. The control task loads and runs the program. It also tells the program which terminal it should run on. MAX III also has no ability to prevent core fragmentation. Core partitioning is used to overcome this obstacle. Half of available core is dedicated to each terminal. The control task assigns a unique name to a program depending on which terminal requested it. Thus, the same program can be running simultaneously in both core partitions. The most heavily used applications programs are described below.

A task called EBD was written for setting up and acquiring data from the 7912's.[6] EBD and most other applications programs start by having the user select the proper accelerator and shot number. EBD then allows the user to assign 7912 channels to signals via an input header table. This table also contains columns for attenuation, monitor calibration, knob settings, vertical position, time shift, and cable compensation for each signal channel. The latest copy of this header is always stored on disc for each machine so the user need only make any corrections via a few simple text editing commands. The program checks all header entries for validity. The program next displays the output header. This table contains a list of all input and output signals along with processing options for the automatic data reduction task. Next EBD checks out knob settings and acquires a baseline for all 7912's used. All setup errors are printed out on the terminal screen. The user has the option to manually inspect and adjust any unit. If this option is selected, the program will continually arm and trigger each selected 7912. After all errors have been corrected, the program arms the digitizers for the shot. After the shot, the data from each 7912 is read out and calibrated. The calibration process consists of:

1. Reducing raw data to a floating point array,
2. Nonlinear time base correction,
3. Fiducial marker location and removal by time shifting,
4. Amplitude calibration by baseline subtraction, and multiplying in deflection factor, attenuation and monitor calibration,
5. Cable compensation.

Each calibrated array is stored on disc for later processing.

The cable compensation mentioned above restores signal high frequency components that are attenuated by transmission over the long cables to the accelerators. The system response for each different type of cable run has been measured. A compensating filter impulse response was then calculated and stored on disc. Input data signals are then directly convolved with the appropriate compensator during the calibration sequence. The longest cable runs have a 3 dB cutoff point of about 70 MHz. The cable compensation extends this out to about 250 MHz. An example of cable compensation is shown in Fig. 5.

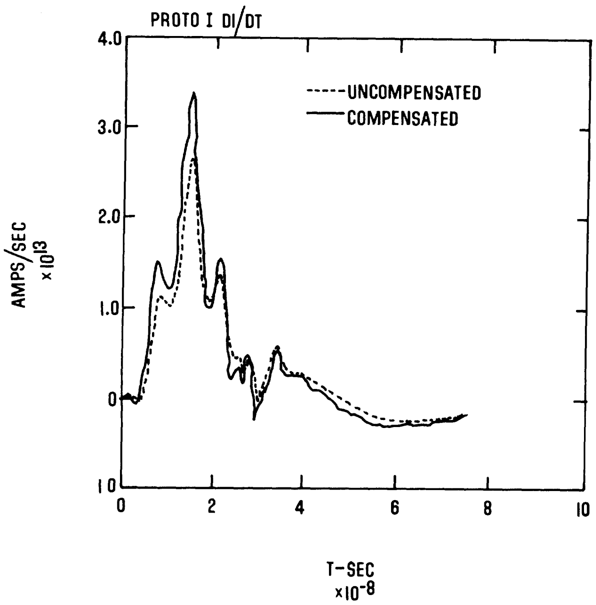

FIGURE 5.

Typical cable compensation input and output waveforms.

A program DIODE is available for automatically processing machine shot data.[7] DIODE will perform a wide variety of operations on shot data depending on which options have been entered in the output header. Typical computations are corrected voltage (V-L·di/dt), impedance, power, and energy. Signal averaging, integration, and baseline adjustment options are available. A least squares comparison subroutine is available for calibrating monitors and computing diode inductances on shorted shots. All data are presented to the user in graphical form. Some examples of DIODE output are shown in Figs. 6 and 7.

The program FAWTEK provides users with powerful capabilities for doing manual data processing.[8] FAWTEK reads mnemonic command sentences from the terminal keyboard. It interprets the command and performs the requested operation. There are currently about 70 commands. They generally fall in one of the following categories:

1. Arithmetic operations
2. 7912 controls
3. Plots
4. Disc access

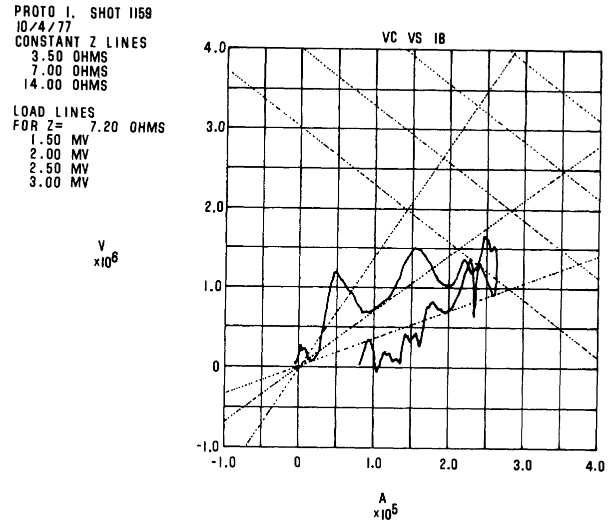

FIGURE 6.

Proto I voltage vs. current with constant impedance and accelerator load lines.

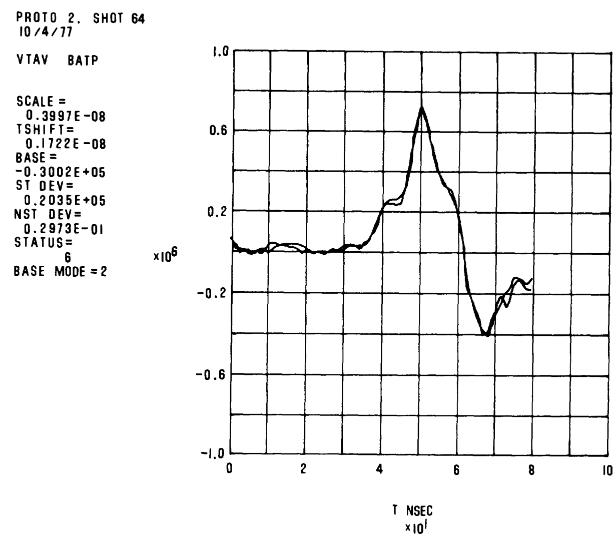

FIGURE 7.

Least squares comparison of Proto II voltage and di/dt monitors to compute machine inductance on a short circuit shot.

5. Tape access
6. Special diode operations

The arithmetic operations available include addition, subtraction, multiplication, division, square root, exponential, log, Fourier transform, least squares comparison, low pass filtering, cable compensation, minimum, maximum, average value, and raise-to-power. All commands operate on at least one entire waveform. Four working array registers are available.

Various plot options may be requested. They include single plots, multiple overlay plots, multiple grids on a page, windowing existing plots and grid definition. Data arrays are read from and written to disc in single random access records. Each machine has a certain area of disc dedicated to it for its own data set storage. Data arrays may be addressed either by record number or output header name. All shot data sets are stored on archive tapes. FAWTEK provides commands for reading and writing these tapes.

In addition to terminal command entry, FAWTEK will also process groups of commands from disc. Users can write programs in FAWTEK command language and store them on a special directoried disc partition. FAWTEK's powerful command set and simple language has virtually eliminated the need for user Fortran programming.

Conclusion

The e-beam fusion research data acquisition facility described in this paper has met its primary design objective. Fully processed shot data is returned to experimenters within a few minutes after each shot. The primary limitation to turnaround time is the rate at which the 4610 and 4631 Hard Copiers can produce plots. Over 3000 shots have been monitored since the facility first came on line in early 1976. The facility hardware and software is designed so the system can be easily run by the experimenters. About 25 different users have run the system at one time or another. This data acquisition system will be essentially duplicated for EBFA. The only modifications will be to include any further advances in computer, digitizer, and operating system technologies.

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