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COMPUTER-BASED DATA ACQUISITION SYSTEM IN THE LARGE COIL TEST FACILITY*

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Abstract: The utilization of computers for data acquisition and control is of paramount importance on large-scale fusion experiments because they feature the ability to acquire data from a large number of sensors at various sample rates and provide for flexible data interpretation, presentation, reduction, and analysis. In the Large Coil Test Facility (LCTF) a Digital Equipment Corporation (DEC) PDP-11/60 host computer with the DEC RSX-11M operating system coordinates the activities of five DEC LSI-11/23 front-end processors (FEPs) via direct memory access (DMA) communication links. This provides host control of scheduled data acquisition and FEP event-triggered data collection tasks. Four of the five FEPs have no operating system. The executable program image is down-line loaded from the host. This stand-alone software permits data acquisition rates of up to 1000 samples/second for 64 fast diagnostic channels. The remaining FEP has an RSX-11S operating system and services 500 slow diagnostic channels on an Analogic Model 5400 at up to 5 channels/second and 800 facility channels from an FX Systems Model 2000 at a rate of less than once every three minutes. Data display is in both numeric (trend log and tabular) and graphical format (e.g., as a function of time or of another channel, stripchart, or bar graph representation on either hard copy or storage tube). Data is stored in raw format, along with the necessary interpretation data bases, on disk or magnetic tape, and/or is transferred to a DECsystem10 via a high-speed link for further reduction and analysis. A sixth LSI-11/23 is used as a satellite processor for driving a DEC VT-11 graphics terminal for simulated real-time display and a CAMAC system used in a voltage compensation circuit calibration. Software utilities are provided for maintenance of the data files, strain gage bridge balancing, sensor signal conditioning calibration, and channel/sensor assignments for given test configurations. This software/hardware implementation has provided a versatile distributed data acquisition and control system with display features for the initial testing sequence of the Large Coil Program (LCP). A remote dual DEC VAX-11/780 system implementation will be utilized for the main testing sequence, with the PDP-11/60 as backup support.

Overview

The LCTF is an experimental facility designed and constructed to test large superconducting magnetic coils of the type and size which could be used in magnetic containment fusion applications [1]. The LCTF and three test coils are being provided by the U.S. Department of Energy from the Large Coil Program in the ORNL Fusion Energy Division (FED). The remaining three coils are being supplied by Germany, Japan, and Switzerland. Each of the six coils represents a different design and construction approach.

Each coil has a combination of approximately 300 diagnostic voltage, current, temperature, strain, displacement, magnetic field, pressure, and differential pressure sensors, all of which are patched via a sensor cable patching network into signal conditioning channels. The coil diagnostic sensors are further defined as "fast" if they require millisecond sampling rates or "slow" if they do not, and they are patched into the "fast" ADAC or "slow" Analogic analog-to-digital converter subsystems, respectively.

The LCTF is instrumented with approximately 800 diagnostic strain, temperature, pressure, differential pressure, flow, and level sensors monitored by the "facility" scanner.

An initial testing sequence will be conducted using two coils (one supplied by the U.S. and one by Japan) to determine the functional operability of the LCTF. The main testing sequence will be used to collect and analyze data from the six coil designs to characterize the strengths and weaknesses of each approach. The initial testing sequence makes use of a PDP-11/60 host computer and appropriate FEPs. The main testing sequence will use a remotely located dual VAX-11/780 as the host.

Data Acquisition System

Data acquisition, display, elementary analysis, and storage are accomplished by the computer-based system shown in Fig. 1. The system consists of seven major subsystems: (1-4) fast coil diagnostic signal preprocessors, (5) a slow coil diagnostic and facility signal preprocessor, (6) control for voltage tap compensation and simulated real-time graphics display, and (7) a host processor and peripherals.

Fast Front-End Processors

FEP hardware systems 1-4 employ the LSI-11/23 CPU and 128 Kwords of memory with no operating system (Fig. 2). The stand-alone application software and the data transfer between the host and FEP is via a PROM bootstrap loader and a direct memory access (DMA) link. A hardware DMA-to-DMA interface card was designed to permit DMA transfers between the PDP-11/60 and LSI-11/23 DMA devices. A software MACRO-11 DMA device driver was written for the FEP to handle communications between the PDP-11/60 and LSI-11/23 which emulates the RSX-11M XB: driver. Two ADAC fully differential, multiplexed, 12-bit A/D converter systems are used with companion DMA controllers to deposit the digitized results directly into the LSI-11/23 memory. A programmable real-time clock is used for timing data acquisition requests from the host and can be started

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by the host to provide synchronization of data collection on the four FEPs. An interrupt interface is used to interrupt the FEP in the event of a transient recording request trigger and to interrupt the PDP-11/60 when a transient recording session is complete. A serial interface for the connection of a terminal is provided for troubleshooting purposes only and is not used during normal operation.

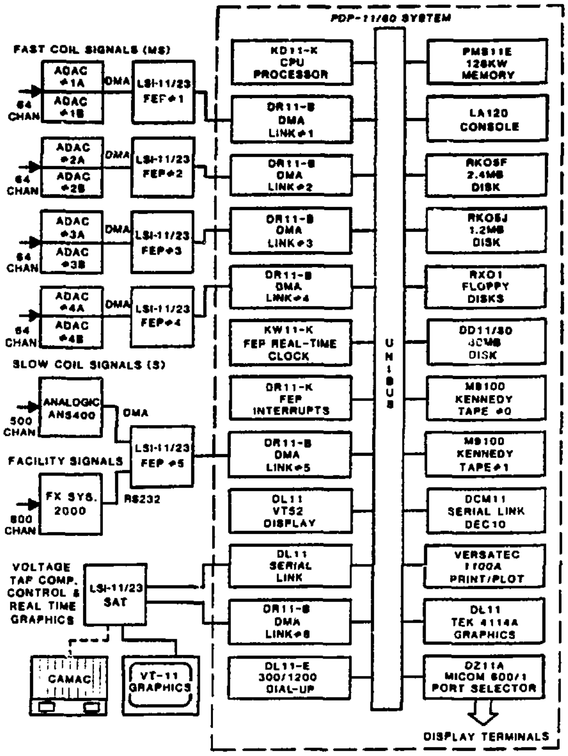

Figure 1. Diagram of LCTF Data Acquisition Hardware.

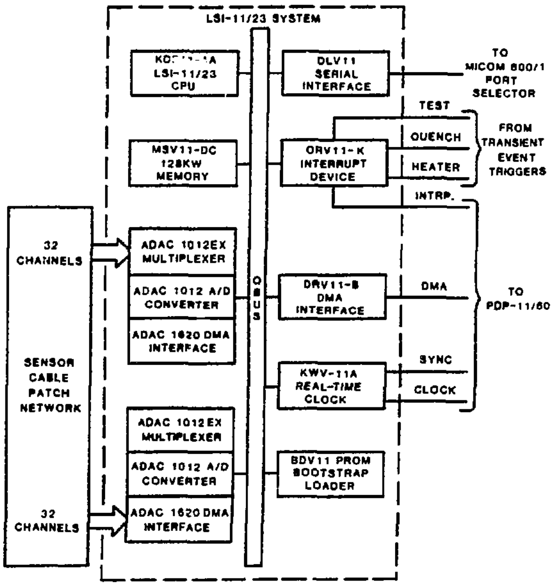

Figure 2. Diagram of LCTF Fast FEP Hardware.

Executing a small stand-alone application program, instead of employing a conventional operating system, allows for higher speed data acquisition during transient recording sessions and increases the amount of memory available for data ring-buffer storage. The application software consists of a 2-Kword program written in PDP-11 MACRO-11 assembly language. The stand-alone software application task [2,3] samples each of the 64 input channels at a programmed pretrigger rate (up to 1000 samples/second) and stores the digitized results in a 122-Kword ring buffer. Periodically (up to once every five seconds), samples of the ring buffer data are averaged and the result is sent to the host for storage, interpretation, and display. Upon receipt of a transient interrupt, the scan rate to the ring buffer increases to permit recording of the transient for a specified number of scans, then drops back to a post-transient sample rate for a pre-defined number of scans. The host is then notified to transfer the buffer of data, which contains a "snapshot" of data prior to, during, and after a triggered event. Once the host has received and stored the buffer of raw data, the software restarts data ring buffering at the pre-trigger scan rate and resumes periodic transfer of averaged data to the host.

Slow/Facility Front-End Processor

The slow/facility FEP 5 utilizes an LSI-11/23 CPU with a 128-Kword memory and the DEC RSX-11S operating system. Its hardware configuration is similar to the fast FEPs with the exception of the two digitizers and the dual RX01 floppy disk system.

The slow digitizer is an Analogic data acquisition system. It provides for 500 fully differential and isolated, signal conditioned, and multiplexed inputs, a 14-bit A/D converter with programmable gain, and controlled DMA to the LSI-11/23 memory. Host-to-FEP communications and data transfer are handled through a slightly modified RSX-11M XB: device driver used in conjunction with the DMA interface hardware. Application software is written in DEC FORTRAN IV and MACRO-11, and is loaded via floppy disk. Data acquisition and control is similar to that of the fast FEPs with the exceptions of the size of the ring buffer (32 Kwords), the sampling rates of 5 samples/second for transient data and every 15 seconds for historical data, and the use of hardware filtering instead of software averaging. A terminal is provided for local control and data display with menu-driven software control of all available data acquisition, display, channel calibration, and diagnostic functions.

The signals from the support facility are digitized using an FX Systems stand-alone multiplexed data scanner. It provides support for 800 conditioned facility signals with a 16-bit A/D converter and RS-232 data transfer to the slow/facility FEP. The operating system is stored in PROM and setup programming is down-line loaded from the host data base system via the slow/facility FEP link. A terminal is provided for local operation, channel calibration, diagnostic functions, and data display with menu-driven control.

Satellite Processor

The satellite processor consists of an LSI-11/23 CPU, 32 Kwords of memory, a DMA link for data transfer, a serial interface for a terminal, and a Q-BUS/UNIBUS translator to drive VT-11 graphic displays and CAMAC voltage tap compensation gain control.

Host - Initial Testing Sequence

Hardware Description. The central or "host" computer consists of a DEC PDP-11/60 CPU with 128 Kwords of main memory, the RSX-11M operating system, and a console terminal. The five FEPs are serviced via DMA links in conjunction with a programmable real-time clock for synchronization of data acquisition. An interrupt interface is used to notify the host of the availability of ring buffer data for transfer service. The VT-52 CRT is used for directing the VT-11 graphics display, by displaying numeric trend/tabular, or bar graph output, and for software programming. Program, raw data, data interpretation, and documentation file storage is accommodated with the Plessy Peripherals 67-Mbyte hard disk and, optionally with the two RK05j/f disks. Archival storage is supported by two Kennedy magnetic tape units. A dual floppy disk system is used primarily to transfer application programs developed on the PDP-11/60 RSX-11M operating system to the slow/facility FEP RSX-11S operating system. A 19.2-Kbaud high-speed link permits the transfer of large data sets to the FED DECsystem10 for access to data analysis codes with greater capabilities than can be executed on the host. The primary data display terminals used by the test and analysis group are the VT-52/VT-11 and Tektronix 4114A with the secondary display on Tektronix 4006-1 terminals. A port selection device is used to provide terminal access to the host, the FEPs, and the FED User Service Center. A dial-up modem is provided for remote access to the LCTF data system.

Application Software and Data Base Structure. Application software on the PDP-11/60 is written in DEC FORTRAN IV+ with menu-driven indirect command file access for operator ease. A few documentation and control data bases were constructed in order to orchestrate data acquisition, interpretation, and preliminary analysis and display of the input signals in the face of changing coil test configurations and sensor patching arrangements (Fig. 3). A sensor assignment file (SAF) contains definition information for all coil and facility sensors. This information includes sensor and signal conditioning identification, signal conditioning and A/D converter gains to be applied, linear conversion factors and/or an index into an intrinsic calibration file (ICF) used to produce the desired engineering units, default plotting parameters, and patching network information up to the first patch point. When data from a sensor is to be recorded, the sensor definition information must be copied into the appropriate channel assignment file (CAF) and the sensor must be physically connected to a signal-conditioning channel through operator instructions available from the patching assignment file (PAF). The CAF is used as an interpretation file for the recorded raw data. The ICF contains special interpretational algorithms for sensors that require more than a simple linear conversion (i.e., platinum, carbon glass, or germanium resistance thermometers and magneto-resistive devices). Since the CAF is modified frequently, it is somewhat susceptible to data entry errors. To minimize the chance of error, the information in the CAF (with the exception of channel/sensor assignments) is usually loaded from the SAF, which seldom changes and contains highly reliable information. The PAF contains sensor, signal-conditioning, and cable patching documentation. When the PAF utility is executed it provides the operator with a hard copy listing of instructions detailing the patching task required to record the sensor signals requested in the CAF. (The signal path from the sensors through the patching network to the FEPs is given in terms of feedthrough connector cable tags, connector numbers, patching cabinet designations, signal-conditioning module name, gain, and switch settings, and FED connector and channel assignments for all fast and slow diagnostic channels.)

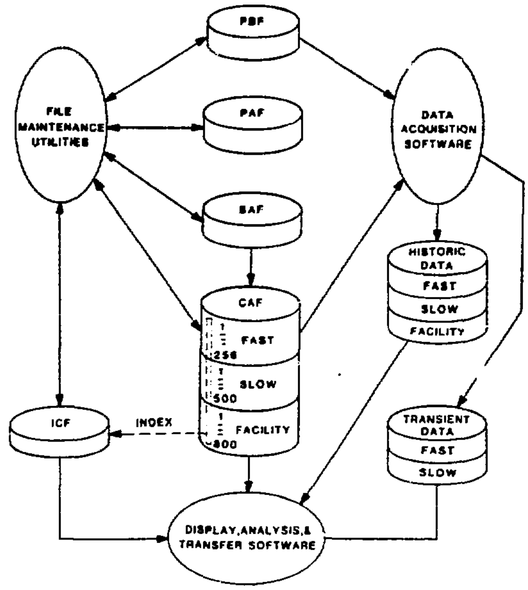

Figure 3. Diagram of LCTF Data Base Configuration.

A parameter block file (PBF) specifies which front ends are to be involved in scanning, which channels on a given front end are to be scanned, and how often they are to be scanned. In addition, this file specifies the "fast" and "slow" FEP pretrigger, transient and post-transient scan intervals, and the number of scans to be taken at each scan rate for each event trigger.

Each data base file system has an associated utility program for maintenance by the operations staff. All data is stored in raw A/D converter counts, with the appropriate interpretation and documentation files providing the appropriate conversion information.

Data integrity is provided through the inner workings of the flexible CAF and PBF coupled with the stable controlling features of the SAF, ICF and PAF.

Data Display Software. Data display is available in graphic form on both direct view storage tubes (DEC VT-11, Tektronix 4114A, 4006) and hard copy (Versatec 1100A printer/plotter or Tektronix 4611) or in numeric form (DEC VT-52, etc.).

The VT-11 graphics feature provides for three types of data displays: (1) a plot of scan data for a user-specified period of time, (2) a plot of channel data from a transient ring buffer, or (3) a simulated real-time "stripchart." Data can be plotted as channel or pseudo channel versus time or channel versus channel in a number of formats (i.e., a selected number of channels from a given FEP may be distributed within the framework of up to four display grids). Any display produced on the VT-11 graphics terminal can alternately be output on the Versatec printer/plotter. The Tektronix 4114A graphics display is similar to the VT-11 graphics discussed earlier without the "stripchart" feature.

A bar graph display represents data as horizontal vectors with the sensor identification along the vertical axis. This display allows a large number of sensors to be compared visually for relative amplitude inspection (Fig. 4A). Two bar graph displays can be shown on a single graph to portray amplitude changes with respect to a shift in time as shown in (Fig. 4B).

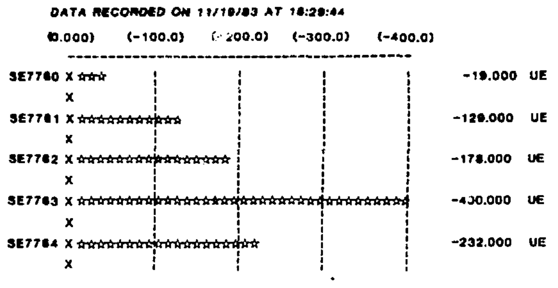

Figure 4A. LCTF Single-Scan Bar Graph Display.

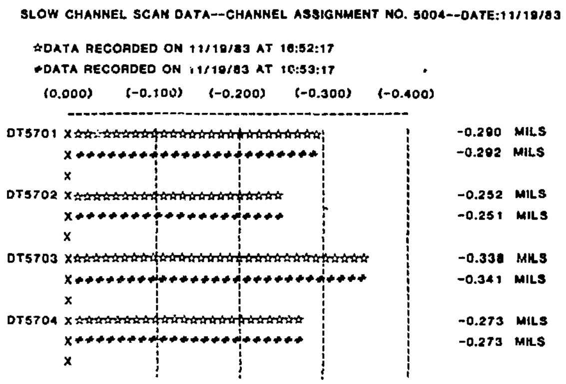

Figure 4B. LCTF Double-Scan Bar Graph Display.

CRT and hard copy numerical display is available in real-time tabular or trend and "snapshot" form. The format for real-time tabular or trend displays is predefined by the operator and updated at the FEP scan rate. The format for "snapshot" data is flexible in that the user can specify the scan or scans to be printed and the particular channels of interest. The printed data can be provided as sensor voltage, A/D input voltage, A/D converter output, post linear conversion or engineering units. Special analysis calculations are performed on pseudo channels entered into the CAF. As an example, the three signals of Rosette strain gage transducers are recorded on three input channels and the results of the Rosette calculation (principal strain, transverse strain, and angle) are placed in three pseudo channels. These display formats provide adequate information for the test and analysis personnel during testing activities.

Post-Test Analysis and Storage. Post-test analysis is performed on the FED User Service Center DECsystem10. The network communications software used to transfer large data files from the host to the DECsystem10 via the high-speed link was developed by FED personnel. Data archival/retrieval routines provide a means of transferring data files from disk to magnetic tape and retrieving them at a later date for further analysis.

Compensation Circuit Gain Algorithm. The LCTF quench detection system utilizes CAMAC hardware to automatically control gain settings for the adjacent coil's pickup coil subtraction (mutual inductance) on voltage tap pairs such that the pure IR signal may be monitored for normal zone detection on a compensated voltage tap pair [4]. The gains are determined by an interactive procedure which initially sets all gains for the pickup coil subtraction to zero or to a value determined in a previous calibration session. Starting with the first coil and selecting each coil in turn, the current is ramped with the initial gain settings and the compensation circuit output voltages are recorded as a function of time during the current ramp, normalized to the uncompensated voltage tap outputs, and averaged (Fig. 5). The gains for all compensation circuits with feedback from the pickup coil (mutual inductance sensor) for the test coil being ramped are changed by an arbitrary amount. Current is again ramped in the same coil and voltages are processed. From the two gain settings and corresponding normalized voltages, linear interpolation is used to compute the gains which will provide minimum compensated voltage tap outputs. This procedure is executed at least twice to reduce the possibility of error. Finally, without adjusting gains, the current is ramped in one or more of the coils and the compensation circuit output voltages are compared with predefined limits to determine if an acceptable minimum has been attained. If not, another pass is made through all coils and the gains are recalculated until acceptable minimums have been attained. The gains are then set manually with thumbwheel switches on the compensation circuit hardware, and the CAMAC hardware is disconnected.

Critical Sensor Monitoring Routine. To aid the test and analysis staff during testing, a critical sensor monitor program has been developed which displays the special coil diagnostic sensor's present, predicted, and red-line values and suggests an appropriate action to be taken by the operations staff.

Host - Main Testing Sequence

During the main testing sequence of the LCTF, the host data acquisition and display task will be transferred to a dual VAX-11/780 system located approximately 1 km from the LCTF. This configuration is illustrated in Fig. 6. An additional CAMAC BiRa Model 1151 Dataway Access Port (DAP) will be added to each FEP to provide the primary DMA access path. Two Jorway Sension display drivers to control HP Model 1351S CRT displays with light pen input will be added for display capabilities. A 1-km fiber optic cable and Kinetic Systems Model 2070 5-Mbaud branch driver will support the communication and data transfer load between the CAMAC hardware and the VAX-11/780 system. A CAMAC software branch driver developed by FED personnel will be used to down-line load the FEPs as well as control data acquisition. An additional eight lines of synchronous/asynchronous communications for terminal access to the VAX system will be installed. A VISUAL Model 102 to provide additional graphics and programming capabilities and a DEC LA120 to log the VAX-11/780 system messages for operator intervention will be added. A high-speed link will be added to transfer plot files to the PDP-11/60 for output on a Versatec printer/plotter.

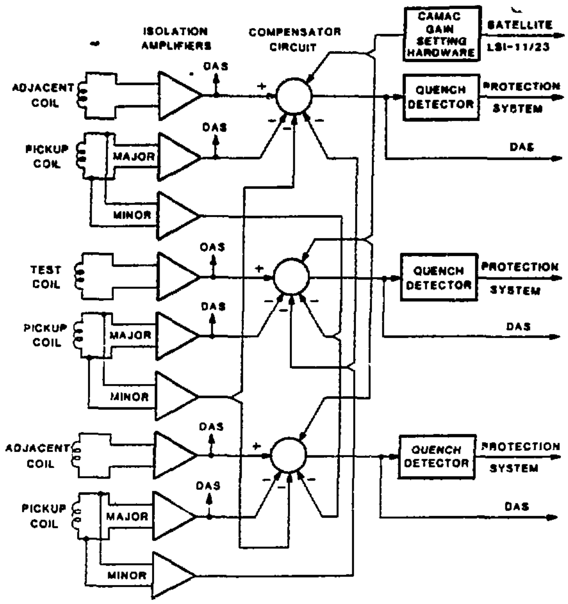

Figure 5. Diagram of LCTF Quench Detection System.

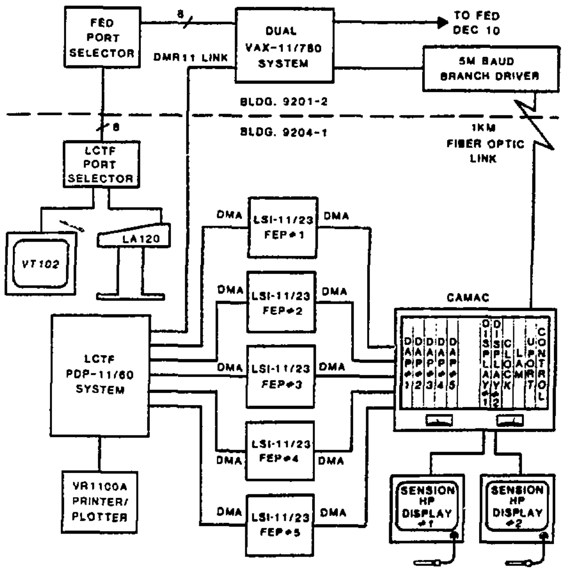

Figure 6. Diagram of LCTF Data System Upgrade

The VAX-11/780 system improves the response time of interactive graphic display, increases post-test data reduction and analysis throughput, provides access to a larger, more flexible data base management system, and adds data system redundancy.

Acknowledgement

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