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J. Wight, A.P. Colleraine, R.M. Hong, J. Kim, R.L. Lee, and J.C. Phillips
General Atomics, P.O. Box 85608
San Diego, California 92138-5608

Abstract: An automated personal computer based CAMAC data acquisition system is being implemented on the DIII–D neutral beamlines for certain diagnostics. The waterflow calorimetry (WFC) diagnostic is the first system to be upgraded. It includes data acquisition by a Macintosh II computer containing a National Instruments IEEE-488 card, and running their LabView software. Macintosh to CAMAC communications are carried out through an IEEE-488 crate controller. The Doppler shift spectroscopy, residual gas analysis, and armor tile infrared image diagnostics will be modified in similar ways. To reduce the demand for Macintosh CPU time, the extensive serial highway data activity is performed by means of a new Kinetic Systems 3982 List Sequencing Crate Controller dedicated to these operations. A simple Local Area Network file server is used to store data from all diagnostics together, and in a format readable by a standard commercial database. This reduces the problem of redundant data storage and allows simpler inter-diagnostic analysis.

1. Introduction

Recent developments in the personal computer (PC) and software industry have brought about inexpensive and powerful alternatives to traditional methods of data acquisition and analysis. In this paper, we present a particular combination of PC-based hardware and software applied to an existing waterflow calorimetry (WFC) data acquisition system. Motivation for changing the original systems was twofold: (1) The desire to add additional features and datapoints to the acquisition set required large scale changes to the existing systems. These systems, based on DEC LSI-11 micro computers with the RSX-11M operating system are already operating at capacity and would be very cumbersome to alter. (2) Recent innovations in the personal computer industry have provided sophisticated and comparatively inexpensive off-the-shelf hardware and software for data acquisition, analysis, and storage.

First, an overview of the particular requirements for the WFC system is presented, followed by a brief review of the previous data acquisition system and its problems. In Section 4, we describe the base system, emphasizing three main issues: (1) How PCs fulfill the need for standardized, speedy hardware. (2) How easy-to-use, off-the-shelf software make the job easier and performs adequately. (3) How Local Area Networks, coupled with commercial databases, address the need for easy data reporting, multiple users, and interdiagnostic analysis. Problems encountered while developing the new system and the future plan to apply it to other diagnostic systems are discussed in Sections 5 and 6, respectively.

2. Diagnostic Requirements

The DIII–D neutral beamline waterflow calorimetry diagnostic [1] was the first system identified for upgrade. The WFC system measures the heat absorbed by beam-absorbing elements of the beamline on a shot-by-shot basis. There exist 20 separate channels per beamline which handle the two independent beam paths from two ion sources. Four such beamlines are located around the DIII–D torus, and thus a total of 80 calorimetry channels are monitored by the WFC system.

During the 300 seconds following a beam pulse, roughly 90% of the energy deposited by the beam is removed by the cooling water. Thermocouples are configured to measure the difference between the inlet and outlet water temperatures for each element. Data for any beam that has been fired within the past 300-second acquisition period is archived, and an analysis summary file is generated for database storage. It is required that the system not become "bogged down" in analyzing one beam at the expense of missing data on another.

Analysis proceeds as follows:

(1) The WFC receives inputs on the flowrate (F_i) and the water heat capacity (C) from a data file, and the beam current (I), the accel voltage (V), and the beam pulse length (t_p) from the main control computer.

(2) A curve fit is made to the ΔT waveform for each shot between $t = 0$ and $t = 300$, the time constant τ_i is determined according to

$$T^{i}_{t>300} = T^{i}_{t=300}\ e^{-(t-300)/\tau_i} \quad .$$

(3) The total energy impinging on each beam absorbing element is computed as

$$E_i = \int_0^{300} F_i C T_i(t)dt + \left[T^{i}_{t=300} - T^{i}_{t=0}\right] C\ \tau_i \quad .$$

(4) The fraction of input energy on each element is derived as

$$\eta_i = \frac{E_i}{I\ V\ t_{beam}} \quad .$$

3. Original System

Figure 1 shows the WFC computer hardware prior to the upgrade. A DEC LSI-11 with the RSX-11M operating system performed the acquisition and analysis. These tasks were developed in Ratfor, a precompiler to Fortran 77. Eight CAMAC crates were employed. Four of these, the remote crates, were on a fiber optic serial highway, each containing a 32-channel digital voltmeter module (DVM), used to sample thermocouple data from a pair of beam paths. The other four, the local crates, each were shared among three separate systems: the WFC system, the beam control computer system (MODCOMP), and the optical multichannel analyzer (OMA) system. The beam parameters were transmitted to the WFC computer from the beam computer via a shared memory module residing in each local crate. One of the local crates also contained a contact input module, generating a set of CAMAC "Look At Me" (LAM) signals whenever a beam was fired. The OMA system received similar shot data and timing signals.

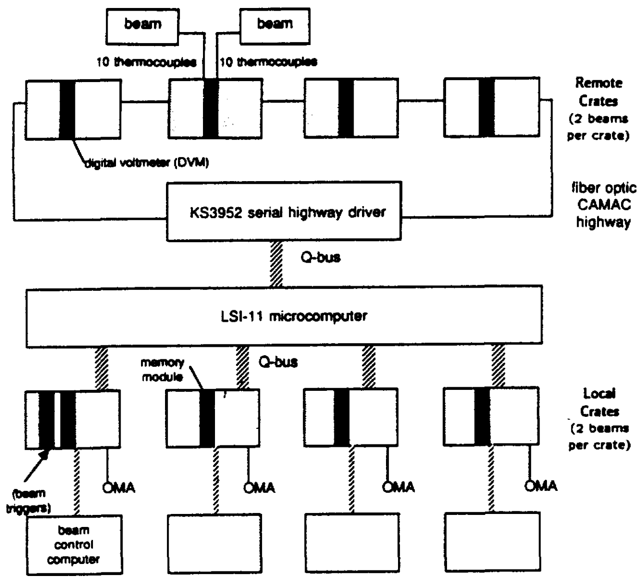

Fig. 1. Hardware configuration of the original WFC system.

4. Description of the New System

4.1. CAMAC

Our large investment in CAMAC equipment forced us to stay with this system as much as possible. As shown in Fig. 2, the serial highway driver (SHD) has been changed from a Q-bus based stand-alone unit (KS3952) to a CAMAC module (KS3992). The four local crates have been replaced by a single, unshared local crate.

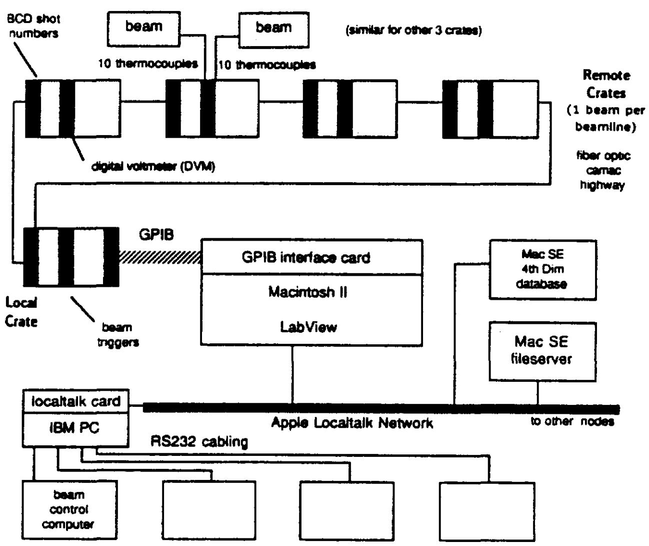

Fig. 2. Configuration of the new WFC system.

In CAMAC terminology, every crate possesses a unique crate number C, each module within a crate a unique slot number N, and each instruction the module is capable of performing a unique address A and function F combination. These four values together comprise the CAMAC instruction (CNAF). To perform a read or write instruction on a serial crate requires two instructions to the Serial Highway Driver (SHD): one to load the CNAF into the SHD instruction register and the other to read or write the data from the SHD data register. Although block transfers (Q-scans or A-scans) are available, the SHD must then be continually polled to find out whether or not each transfer has completed. Each thermocouple channel in the DVM requires two reads; thus, to read 20 channels per DVM per second for all four DVMs requires 320 CAMAC executions per second. Software efficiency is therefore critical.

4.2. List Sequencing Crate Controller

Much faster acquisition over the serial highway is attained by using a KS3982 List Sequencing Crate Controller (LCC). This module can perform up to 512 pre-loaded dataway operations at user-selectable rates of between 5000 and 1 million per second. Upon demand from the WFC computer, made once per second, the LCC collects and stores all thermocouple data. Between each demand the WFC computer efficiently reads in all the stored data with a single block transfer. Since this takes place within the local crate, the bottleneck of the SHD is avoided.

In the WFC system, the LCC is used in conjunction with two memory modules, as shown in Fig. 3. Conceptually, reading each DVM channel is a four step sequence which begins by obtaining an NAF from the instruction memory module, and ends by writing the acquired data to the data memory module. By making use of a special repeat feature of the SHD, the cycle can be shortened after the first channel of the DVM has been read; subsequent channels can be read by simply repeating steps 3 and 4. The LCC instruction list is encoded into 24-bit words, each representing an NAF. Branching and conditionals are not supported. A spreadsheet is used to perform the encoding, and upon WFC initialization the list is written to the LCC.

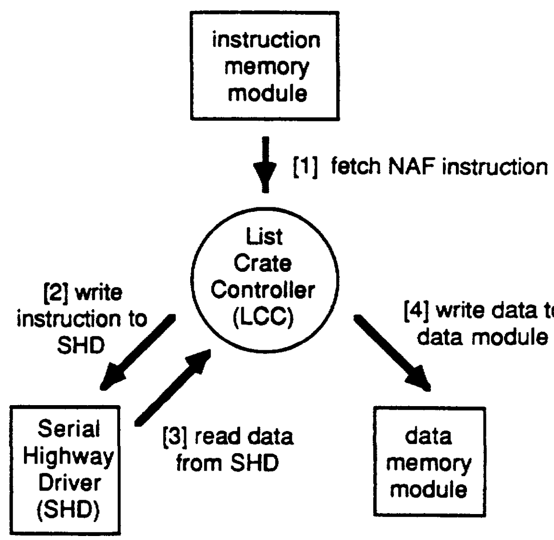

Fig. 3. List crate controller sequence.

4.3. Computer Hardware

The PC selected for the WFC system is the Apple Macintosh II, chosen on the basis of ease of use, cost, ease of networking, and large scale availability of useful commercial software. A National Instruments model DMA-8-G General Purpose Instrument Bus (GPIB) card is plugged into one of the Mac NuBus slots. This card is rated to carry out up to a million GPIB instructions per second, using Direct Memory Access (DMA) to move data in and out of Macintosh memory without having to pass through the Mac CPU.

The WFC Macintosh is a part of the Local Area Network (LAN) comprised of nearly 20 Macintoshes and an IBM PC [2]. The Apple LocalTalk network is rated at 232 kBits/second transferred over simple twisted pair phone wires. The IBM PC is directly connected to the four beam control computers (MODCOMP-Classic) via RS232 cabling, and is connected to the LAN via an AppleTalk PC card and software.

4.4. Software

All acquisition is performed through National Instruments' LabView software. Programming within LabView revolves around creating "Virtual Instruments" (VIs) on the Mac screen, which have "Front Panel" and "Wiring Diagram" windows. The front panel consists of switches, meters, light bulbs, and other indicators and controls that might appear on the front panel of any real instrument. In the wiring diagram, "terminals" from the various front panel elements, as well as other VIs are wired together to produce the desired functionality. When the VI is operated, the switches and knobs are controlled with the Macintosh mouse, and the indicators are updated in real time.

The WFC front panel [Fig. 4(a)] is used to check the system status. Although all 80 ΔT channels of all eight beams are always "online," the front panel reflects the status of just one thermocouple of one beam at a time, selected with the slider controls. The "integrating" light indicates whether or not data is currently being stored for the selected beam, and the "counter" indicator provides a countdown readout of the 300-second clock. The shot number, water flowrate, and the portions of the analysis integral are shown in the other indicators, and a "strip chart recorder" at the bottom displays a time history of the temperature on a semi-log plot.

The programming of the VI is accomplished through the wiring panel [Fig. 4(b)]. LabView's visually based programming language allows the user to place icons representing the front panel controls and indicators, as well as sub-VIs (either supplied by National Instruments or user defined) on this panel. Various program control loops can be formed, and the icons are all "wired together" so that data flows between them in a user definable fashion. The WFC VI is composed of 22 user-defined sub-VIs and many more supplied by National Instruments. The wires are of various widths and shading, indicating the type of data flowing through them (numeric array, boolean, etc.). The large rectangles of various styles are the program control loops. Shown are the *sequential loop* (first frame 0 executes, followed by frame 1, etc.), the *while loop* (executes until the small circular arrow becomes false) and the *case statement*. Not shown but also available is a *for loop*. With these four structures virtually any control logic can be constructed. Building sub-VIs is identical to building the main VI, with the addition of needing to draw its icon and define the wiring "terminals" through which data is transferred. Sub-VIs can be thought of as subroutines in a more traditional programming language, and are useful for the same reasons: to re-use often needed sequences, and to keep the VI modular and understandable.

4.5. Networking

The Apple LocalTalk LAN plays a crucial role in the WFC data analysis, providing two essential services: passing beam parameters from the control computer to the WFC system via an IBM PC [2], and storing the analyzed data in a centralized data management system. The main responsibility of the IBM PC is to gather historical data from the beam control computers after every neutral beam shot. Special software has been written for the IBM that continually polls the serial ports for incoming beam data, which totals about 2 kByte per shot per beam.

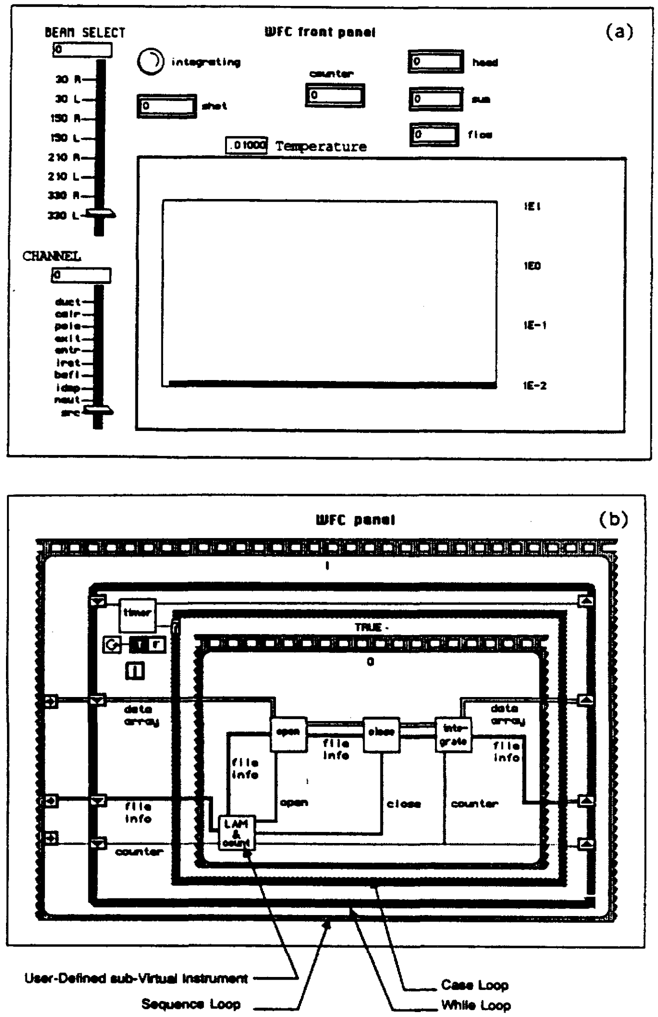

Fig. 4. A view of the Macintosh II screen (a) WFC front panel; (b) main WFC wiring panel (only certain layers visible).

Selected portions of the data are stored on the network file server, accessible to any computer on the network. In this way the WFC system has access to the shot number and beam identification, the I V t_p parameters, and the beam perveance.

Also residing on the file server is a neutral beam database created with Acius' 4th Dimension, a commercial multi-user relational database manager for the Macintosh. NBdat, an application written in the 4th Dimension language, is available to any Macintosh on the network. NBdat is responsible for several tasks: (1) Carrying out the computation of Step 4 of Section 2. (2) Storing and retrieving user comments pertaining to any WFC or beam data. (3) Report generation. Either pre-defined or ad-hoc graphs and summaries are easily performed. (4) Online analysis. While LabView is acquiring data on the WFC Mac, previous data can be reviewed on any other machine on the network. (5) Interdiagnostic analyses. NBdat will be common to all upgraded systems, enabling reporting and analysis of quantities derived from separate diagnostics.

5. Problems Encountered

LabView has certain shortcomings. There are no global variables in the LabView environment; every value that is passed to a VI must come through its connection terminals. The use of multi-dimensional arrays can help reduce the multitude of wires joining the icons, but extreme care must be taken to build and index these arrays in the right order.

Interrupt servicing poses another problem in LabView. Simultaneous operation of VIs are not supported, nor are there provisions for attaching VIs to execute automatically in response to interrupts. The main VI program cycle must therefore contain any interrupt provisions. The WFC LAM interrupts are serviced once per second, the rate of the main VI cycle. Since several seconds pass before the heated water reaches the thermocouples, this response time is acceptable. For other systems requiring fast response times, maintaining fast enough interrupt polling may become tricky.

Two 24-bit IO612 input/output modules are needed in the local crate of Fig. 2 simply because the SHD needs 24 bit data to address the highway (bits 17 to 24 of the SHD instruction register contain C, the crate number), yet there are presently no 24-bit CAMAC memory modules on the market. A bug in the LC8201 memory module requires a "dummy read" to be executed whenever the pointer is moved to re-enable its pointer auto-increment. A third IO module is required merely as a convenient dump for this dummy data.

The present version of the 4th Dimension database is slow at importing the WFC data (about 2 seconds per record) as well as generating reports. Its relational links are one-directional only, limiting the structure of the database layout.

6. Future Plans

The Mac-LabView combination was successfully applied to improve the WFC system. It can also serve as a model for other diagnostics in the DIII–D neutral beam system. Here are three possibilities: (1) Remote and automatic operation of a Residual Gas Analyzer system is currently under study. Four RGAs would be directly controlled by using a GPIB fiber optic highway. (2) The DIII–D armor tile infrared camera imaging system, at present not computerized, would make use of an video image processing board, several of which are available for the Nubus. (3) The OMA system is similar to the old WFC system: an LSI-11 computer, four remote crates on a fiber optic highway, and four local crates (formerly shared with the WFC system). Although the OMA aquisition is simpler than the WFC system, with data buffered within the OMA instrument itself, the mathematical analysis is much more involved, and therefore the speed and the variety of the data reduction is crucially important.

Each neutral beam operator's console now contains a Mac II as an interface between the beam control computer and the operator [3]. When connected to the LocalTalk network, comments entered into the interface computer can be stored in the NBdat database. Diagnostics could also notify the interface computers when analysis was complete, alerting the operators or automatic systems that another shot could be taken. Any long-range plans for neutral beam data analysis must include the integration of all beam diagnostic data with the extensive DIII–D physics database on the DIII–D VAX cluster. Hardware and software is available for attaching LocalTalk to VAX networks so that VAX resources can be partitioned onto "Virtual Disks" on a LocalTalk network, and software for Macintosh manipulation of VAX-based databases is becoming available.

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