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Introduction

In October of 1981, the construction of the Mirror Fusion Test Facility (MFTF) at Lawrence Livermore Laboratory in California is scheduled to be complete. Soon after, LLL physicists will use the facility to produce plasmas to study scaling laws and other properties of large mirror-confined plasmas. MFTF plasma diagnostics will supply the means by which the plasma will be studied and also some computer power to help analyze the large amount of information collected from each plasma shot.

The initial goal of the Data Acquisition System (DAS) is to control 11 instruments chosen as the startup diagnostic set and to collect, process, and display the data that these instruments produce. These instruments are described in a paper by Stan Thomas, et. al. entitled "MFTF Plasma Diagnostics System." The DAS must be modular and flexible enough to allow upgrades in the quantity of data taken by an instrument, and also to allow new instruments to be added to the system. This is particularly necessary to support a research project where needs and requirements may change rapidly as a result of experimental findings.

Typically, the startup configuration of the diagnostic instruments will contain only a fraction of the planned detectors, and produce approximately one half the data that the expanded version is designed to generate. Expansion of the system will occur in fiscal year 1982.

System Overview

From the bottom up, the Plasma Diagnostic Data Acquisition System (DAS) consists of about 100 detectors (Table 1) linked to analog electronics hardware 50 meters away in a screen room. The electronics (almost entirely in CAMAC and NIM modules) connect to various-speed A/D converters, pulse counters, PHA equipment and transient recorders, most housed in CAMAC crates. From the crates in the screen room, a group of 50 - 75 meter fiber-optic serial CAMAC links ("serial highway"), about one link for each diagnostic, connects to LSI-11/23 Diagnostic Controllers (DC's). These DC's then connect to an Interdata 8/32 (DDP) that is dedicated to plasma diagnostics (see Fig. 1).

The Diagnostic Data Processor (DDP) is part of a network of three other Interdata 8/32 processors and five less powerful Interdata 7/32 processors that provide control for, and collect data generated by, MFTF machine operations and the plasma diagnostics instruments. Two of the Interdata 8/32 computers will be heavily involved with the Plasma Diagnostic System. The DDP, as mentioned, will communicate with, and pass control information to, each instrument's Diagnostic Controller. It will also collect and do preliminary processing on all the data sent by the diagnostic instruments (through the DC's). The

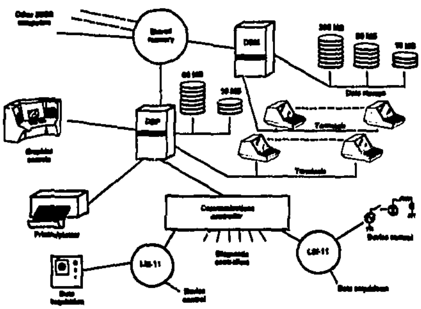

Fig. 1. Plasma Diagnostics Computer Control and Data Acquisition

Data Base Manager (DBM), primarily involved with storing, retrieving, and processing diagnostic data, will also act as the system bookkeeper for the network of nine computers.[1,2]

Environment

Radiation

MFTF presents a particularly hostile environment for diagnostic instruments. Conditions that must be dealt with include significant neutron radiation, high electrical noise, and large dc and pulsed magnetic fields. A one-half-second MFTF shot will produce approximately 5×10^9 neutrons per cm^2 at a distance of 6 m from the plasma. This corresponds to a cumulative dose of approximately 10^6 rad (C) over the ten-year lifetime of the facility. Commonly used organic materials, such as Teflon, are unusable in the vault; and others, such as polyethylene, are marginally acceptable. Semiconductor detectors and electronics soon fail without neutron shielding. Other detectors, such as surface-barrier detectors, also need shielding, and they can produce overwhelming background signals when exposed to the expected neutron flux.

Magnetic

The yin-yang configured superconducting magnet produces large fringing fields of about one kG at the vessel wall and 300 - 400 G at the end domes. Every diagnostic that involves the motion of charged particles must account for these fields or shield against them. Photomultiplier tubes must be shielded to less than 1 G. The magnet will distort under the stress of cooling and energizing, which necessitates provisions for remote sensing and realignment of some diagnostics.

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Table 1. Plasma Diagnostics Initial Set

Diagnostic	DC	Detectors Type	Number	DATA 4 KS Burst Chans	Standard Chan	PHA Chan	Total Data KB
A Neutral Flux Spectroscopy	1	Daly Type	6	6	6	1	107
D Neutral Beam Transmission	1	Faraday cups	40	-	40	-	300
F Thomson Scattering	1	PM Tubes	12	-	12/10	-	2[a]
G Diamagnetic Loops	1/3	Loops	4	-	4	-	30
H RF Noise	1/3	Probes	10	8	10	-	115
I End-Loss Spectroscopy/ Bolometry	1	Charge Collection and Pyro Electric	2 8	- -	- 8	2 -	80 60
K Background Gas Pressure	1/3	Vacuum gauge	4	-	4	-	30
L Laser Interferometry	1	Hg Cd Te IR Detectors	7	7/16	8/16	-	136
M Soft X-ray Spectroscopy	1	Surface Barrier Detector	1	-	-	1	40
O Photon Imaging	D	MCP-Vidicon	1	-	-	-	0 900 kilobytes

Resolution: The burst channel resolution is 10 bits/sample. The standard channel, except where noted, is 12 bits/sample. The PHA channel is 20 bits per bin and 256 bins per spectrum.

Speed: The standard channel samples at a 10-kHz rate. The burst channel samples at a 1-MHz rate. The PHA takes a spectrum every 8 milliseconds.

a Thomson Scattering takes only 32 samples.

Vibration

Machine vibrations with amplitudes of hundreds of micrometres at frequencies up to 1 kHz are expected. This requires dynamic path-length measurements and possibly dynamic corrections to be made for laser interferometry.

Electrical Noise

Neutral-beam sources and plasma-streaming guns each require high current and high-voltage pulsed power, and--combined with the heavy machinery in the conventional facilities--they produce a very noisy electrical environment. For this reason, signals will be run on doubly shielded twisted pair or triax and enclosed in grounded conduits. The diagnostic system will be strictly ground-isolated from the vessel and associated machinery. Diagnostic electronic instrumentation is enclosed within an RF-shielded room that will be supplied with isolated electrical power.

Remote Operation

Proximity

Due to the high, quasi-permanent magnetic field from the MFTF superconducting magnet, the main control and diagnostics building with its graphics consoles was moved from a location close to the vessel to approximately 75 m from the MFTF containment vessel wall. The diagnostics front-end electronics and data-conversion equipment were not moved. Instead, they were placed as close to the vessel as possible to avoid long cable runs. The front-end electronics equipment is placed outside of the vault to avoid the resulting shielding cost and access problems.

This equipment is totally electrically isolated from the control room by serial fiber-optic links. This is highly desirable because the control and diagnostics building, which contains all of the MFTF's computers, will not be subject to electrical noise introduced by signal spikes or improper grounding of diagnostic equipment.

Remote Testing and Calibration

Human occupation of the immediate area surrounding the MFTF may have to be prohibited or at least limited, hence, the requirement that all important parameters of the DAS be computer readable. Wherever possible, the DAS equipment will also be remotely programmed and remotely tested. For example, a method is being developed to allow the injection of calibrated test signals into the front end electronics to allow end to end testing of each channel. The end-to-end gain may be experimentally checked, the linearity of A/D equipment verified and thus the readiness of the data channel demonstrated.

Physicist Interaction

The normal knob-twiddling that takes place in every diagnostic room preceding large physics experiments will be largely absent from MFTF. The standard man/machine interface for MFTF plasma diagnostics is a general purpose graphics terminal. This terminal will be physically connected to the DDP or DBM, and it will communicate with the Diagnostic Controller (DC) through a high-speed serial data link. All parameter changes sent to the DC will be screened for appropriateness before becoming effective. Set-point information will be returned by the DC and will then be entered into the data base along with a time stamp. Physicists will be able to interrogate and alter any controllable parameter of each data channel including the following:

- Front-end gain.
- Timing parameters.
- Burst triggering.

They will also be able to monitor and display instrument parameters that include the following:

- Power-supply voltages.
- Power-supply currents.
- Vacuum measurements.
- Temperatures.
- Positions.
- Interlock status.

With the DBM facilities, a user can program an instrument in the same way he or she sets the station on a pushbutton car radio. Then each parameter of the system is carefully adjusted to the satisfaction of the physicist, a command is entered to save all parameters. Along with the information saved is a comment field and date. The exact channel setup (barring cable rearrangement) can be recalled simply by entering a restore command. In fact, the exact setup for each channel will be saved along with the raw data from each shot.

Diagnostic and control data from recent past shots will be accessible to all on-line terminals. Very old shot data may be retrieved from magnetic tape. Machine control parameters from past shots and up-to-date information on the current or next shot are similarly accessible. This information can help physicists to properly set up each diagnostic. For example, gain settings on signal amplifiers, or filter selection will be set according to the type of plasma expected.

Operating Scenario

Personnel

Three groups of physicists--numbering between 10 and 15--will work on MFTF. Each group will have rotating turns of about two weeks each for the 13-week run period. A five-week scheduled maintenance period will provide time to bring the vessel up to air to replace sensors, service vacuum and cryo equipment, and install new equipment. The operating crew at any one time will consist of trained machine operators, physicists conducting the experiment, and physicists analyzing data taken previously.

During a shot sequence, two lead people will be responsible for the successful operation of the MFTF machine; one for facilities operation and the other for the physics experiment. The lead operator will have direct access to the system supervisor console and will be responsible for issuing orders to the operators on all other consoles to bring about and maintain the desired set of operating parameters for MFTF. The lead operator will be able to call up any status display available in the control system and will have the authority to cancel a shot if he feels that MFTF is in an unsafe condition.

A lead physicist at the physics graphics console will be responsible for selecting the machine parameters, the diagnostics, and the intershot reduction programs to be used on the next plasma shot. This physicist will have the authority to change machine parameters such as beam aiming or timing, to exclude diagnostics from an experiment, or to command the resources of the DDP as appropriate.

A clear channel of control must exist between the individual physicist and the machine operators. Physicists will request machine changes through the lead physicist, and operators will receive parameter change requests through the lead operator. This arrangement requires a very closely linked working relationship between the lead physicist and lead operator and further requires that their display consoles be adjoining.

Standard Channel

There is a fundamental conflict between the desire to collect all reasonably obtainable information from an instrument and limitations on available memory size, channel bandwidth, and funds. Fulfilling the desire requires sampling at least twice as often as the highest frequency that can pass through the detector and front-end electronics. All these data must then be stored for later reference; in fact, storage is the key. Even though the state of the art is pushing sampling speeds up and storage costs down, it is still impractical to store the 750,000 bytes of data per channel that occurs from a 12-bit 1-MHz A/D sampling for a 0.5-s plasma shot. The transmission costs, processing requirements, data base management problems, and floor space needed to house tape vaults for the 500-ms shot are not justified by the need to perceive the fine structure of only a 1-ms segment of one or more channels.

Yet, the need for fine detail is valid. The approach being considered on a standard MFTF channel will be to sample simultaneously with a slow A/D (~100-μs period) and a fast or burst A/D (~1-μs period). The slow A/D samples continuously throughout the shot, collecting 5000 samples and providing a coarse overall picture of the channel's activity. The burst channel has a total memory of 4000, but it need not sample continuously. A burst controller initiates the collection of 128 contiguous samples and time stamp the start of sampling to allow comparison of traces between channels.

The requirements of the burst controller are currently being developed. Two that have emerged involve the triggering mechanism. In one, external events trigger the burst collection. This self-triggering scheme ensures that only important data are collected, but synchronization with other channels on the same or different instruments is difficult. The other triggering scheme calls for initiation to be controlled by preprogrammed time sequences. This allows many channels to be linked to follow wave phenomena but requires advance knowledge of the data to be collected.

Modularity

An LSI-11/23 controller for each diagnostic allows a modular approach to implementing diagnostic instruments on MFTF (Fig. 2). The modularity arises from the ability to perform tasks common to all diagnostics with a set of programs to be used in each DC. Each DC looks like all other DC's in terms of hardware configuration, communications interfaces, and software. The main elements are as follows:

- Protocol and hardware for the DDP-DC communications link.
- CAMAC serial link hardware and software driver.
- The executive software in the DC.
- The set of primitive functions that the DC can perform (e.g., open valve or read pressure gauge).

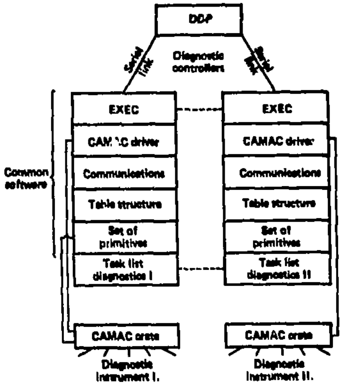

Fig. 2. Flexibility is Achieved by a Modular Approach

Specific driving routines for each supported CAMAC module type form a repetory of primitive functions that reside in the executive.

From the viewpoint of the DC, the inclusion of a new CAMAC module entails adding that modules primitive function to the executive (a recompile of the system) and the downline loading of a task calling for the operation of the new module.

Summary

- The physics work area and diagnostics control room are physically remote from the diagnostic electronics.
- Dedicated computer control of each instrument has been adopted.
- Modularity is stressed in the design of the Diagnostic Controllers.
- The physicists primary interaction with any aspect of the DAS system is through a graphics terminal.
- High neutron fluxes create detector, electronics, and cabling problems.
- Strong local magnetic fields and high ambient noise have required the use of a screen room.
- A twofold approach to data taking involving a fast and slow A/D is being used as a standard channel.

References

1. J. H. Choy and J. A. Wade, "A Data Base Management System for the MFTF," Proceedings of the 8th Symposium on Engineering Problems of Fusion Research.

2. J. A. Wade and J. H. Choy, "Control and Diagnostics Data Structures for the MFTF," Proceedings of the 8th Symposium on Engineering Problems of Fusion Research.