Improved Operating Scenarios of the DIII–D Tokamak as a Result of the Addition of UNIX Computer Systems*

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ABSTRACT

The increased use of UNIX based computer systems for machine control, data handling and analysis has greatly enhanced the operating scenarios and operating efficiency of the DIII–D tokamak. This paper will describe some of these UNIX systems and their specific uses. These include the plasma control system, the electron cyclotron heating control system, the analysis of electron temperature and density measurements and the general data acquisition system (which is collecting over 130 Mbytes of data). The speed and total capability of these systems has dramatically affected the ability to operate DIII–D. The improved operating scenarios include better plasma shape control due to the more thorough MHD calculations done between shots and the new ability to see the time dependence of profile data as it relates across different spatial locations in the tokamak. Other analysis which engenders improved operating abilities will be described.

INTRODUCTION

Under contract with DOE, General Atomics operates the DIII–D tokamak, a large device to explore magnetic confinement of plasmas. First operation of DIII started in 1978 and the upgraded machine DIII–D began operating in 1986. Results from DIII–D experiments are needed to gain an understanding of the behavior of plasmas at thermonuclear temperatures, and for the design of future machines, including International Thermonuclear Experimental Reactor (ITER), and for the ultimate successful use of fusion energy. During the 1980's, new computers were acquired and installed for computation and for control of the DIII–D tokamak. Many of these new computers were a Digital Equipment Corporation VAX system (11/780, 8650, microVAX II, 6310, 4000-300 and other models). As our need to do faster computation grew, the existing VAX computers were no longer able to handle these computations. UNIX systems were brought in at first for some special purpose needs, and later for more general usage. The first UNIX systems were used in 1990. Since then, approximately 32 UNIX systems have been added and are in service now. See Table I for a partial listing. Many collaborators are now bringing UNIX systems with them, both for diagnostic control, and for analysis. This number is constantly increasing. These UNIX machines have enhanced the ability to operate the DIII–D machine, since more data can be collected, and it can be analyzed more thoroughly between shots in order to optimize experimental operations.

Table I
A Partial List of UNIX Systems and Their Functions

CPU Type	Usage
Motorola 88110	General data acquisition (100 Mbytes/shot)
Motorola 88110	General control, power supplies, etc.
Motorola 88110	Neutral beam control and acquisition
Sun-4 clone	Plasma control system
Sparc-2 clone	Plasma control system
Sparc-2 clone	Charge exchange recombination data collection
SUN Sparc-10	Fast wave current drive
HP 730	Analysis of Thomson laser data
SUN Sparc-10	ICH heating
HP 735/125	Between shot analysis
HP 730	EFIT MHD code development
HP 730	Theoretical analysis
HP 730	RF analysis
HP 735	EFIT runs and plasma control system
HP 735	110 GHz gyrotron control
HP 735/125	ONETWO transport analysis
HP 710	COSMOS, small jobs
HP T500	3 CPU general cycle server
SGI Indigo	Code development and graphics
SGI Indigo	Code development and graphics
GI Indigo	Code development and graphics
SGI Indigo	Video and control of lithium beam
SGI Indigo	MBONE, video applications

PLASMA CONTROL SYSTEM

One of the first UNIX systems to be used is in the plasma control system (PCS) [1–4]. This system consists of a several Sparc processor boards, Intel i860's processors with data acquisition daughter boards, D/A converters, and digitizers in a VME crate. This high speed digital data acquisition and processing system was designed for feedback control and analysis of plasma shaping. It was rapidly successful because of its ease of use and flexibility. Additional benefits gained from the use of UNIX systems include the ability to communicate with other systems, share data, send messages for control and status, and use other CPU cycles for computation when they are available. The plasma control system has been used to do experiments that were difficult to configure and/or control with previous systems, and which enhance the ability to operate the DIII–D tokamak. Two of these uses are described.

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The PCS was successful in controlling the time evolution of plasma stored energy by pulse width modulating the injected neutral beam power. Control of stored energy resulted in substantially improved plasma performance.

The PCS was used to optimize the coupling of Ion Cyclotron (ICRF) waves to the plasma by calculating antenna loading from forward and reflected voltage measurements. The PCS adjusted the gap between the plasma and the antenna for constant antenna load. This allowed the absorbed power to be maximized.

Recent improvements [5] to the plasma control system allow for active control of a large number of plasma parameters. These include plasma shape and position, total stored energy, density, RF loading resistance, radiated power and more detailed control of the current profile. Experiments may be more accurately controlled and each experiment can be conducted more effectively.

DATA ACQUISITION SYSTEM

A year long effort concluded with the replacement of three proprietary computers by one computer (DAQS) which is responsible for the bulk of digitizer control, data collection and data formatting [6–7]. This one new computer is running a System V version of UNIX, and has a VME bus and controller connected to existing CAMAC equipment. One enhanced serial highway is installed and a second will be added in late FY95. There were many benefits to be reaped by converting to a fast, reliable UNIX system. These are summarized in Table II.

Table II
Benefits of Converting to UNIX DAQS

Fast code development due to increased CPU speed
Ability to develop on desktop and move to DAQS CPU
Ability to write window based applications using various available software
Use of standard languages — largely C
Cross over skills from other UNIX systems
Easy development of client/server software, esp. with other UNIX systems
Ability to use software developed on other systems (specifically the IPCS system for asynchronous messaging developed at LLNL [8])
Ease of networking and relative speed of TCP/IP
Compatibility with existing CAMAC equipment
Ability to configure multiple CAMAC highways (2 highways are 1.99 times as fast as 1 highway as the I/O overlap is nearly total)
Speedup by a factor of 4 or more in data acquisition
Availability of data base software at a reasonable cost
CPU cycles available for various compute purposes
Excess I/O cycles available
Ease of expanding hardware for our needs (new disks, additional CPUs, more memory, additional ethernets)
Reliable operation of hardware
Ease of system maintenance (both hardware and software)

The new DAQS has been in operation for approximately a year. Data of over 130 Mbytes for a 4 second tokamak pulse has been collected. The total time for data acquisition, data checking, data formatting, addition of timing information to the data, and writing disk files is approximately 6 minutes. The amount of system downtime has been minimal, and was largely due to unanticipated software problems, somewhat related to learning the foibles of a new system. The stability and productivity of this system have exceeded our expectations. The CPU and I/O speeds have made it possible to collect more data very quickly, without negatively impacting the total time between shots, and to have capacity for future expansion.

FAST WAVE CURRENT DRIVE SYSTEM

The Fast Wave Current Drive (FWCD) control system is run on a SUN computer under the Solaris operating system [9]. A primary reason for choosing this platform was the desire to use LABVIEW for control, to have a true multi-user, multi-tasking environment, and to have very good communication with all of the other computers and data associated with the DIII–D experiment. The use of a UNIX operating system and LABVIEW allowed the FWCD to be quickly added to the DIII–D environment. The following services have been developed for several UNIX operating systems and were installed on the FWCD system as part of its experimental control: routine backup across the network, software libraries to generate data files for standardized access, access of shot data on any other computer at the GA site, automatic collection and archiving of shot data, automatic management of disk space and data files, and synchronization with tokamak events.

With the UNIX operating system, simultaneous code development and hardware operation occur. Multiple data interfaces and communications protocols are also occurring simultaneously, which is a requirement for operating the hardware. GPIB (general purpose interface bus), CAMAC, serial, VXI (VME eXtended Interface) and ethernet connections are used to interface with the various types of hardware [10]. Two megabytes of data is collected during tokamak shots, and this data is immediately scanned using codes developed on other UNIX systems. The data is used to automatically adjust the antenna gap between shots. This allows the FWCD to be quickly synchronized and used for heating of DIII–D plasma shots.

MOTIONAL STARK EFFECT DIAGNOSTIC

The Motional Stark Effect diagnostic (MSE) allows the q profile to be routinely measured for DIII–D plasma shots [11]. Measurements of the polarization of light emitted from injected neutral beam particles are used to deduce the magnetic field properties inside the plasma. Both the stability and confinement properties of the plasma depend on the q profile, which is a measure of how much the magnetic field lines twist. In a strongly shaped tokamak like DIII–D, the overall shape of the magnetic surfaces and the exact current and q profiles cannot be determined directly from the MSE measurements. Instead, the MSE and external magnetic measurements are fed into the equilibrium reconstruction code EFIT, which determines the plasma profiles that best fit the data. The additional UNIX cycles make it possible for EFIT to run in between shots on DIII–D to quickly evaluate the q profile. Using this improved capability, DIII–D has been operated in a new inverted q profile configuration. The MSE system also gives information about the distribution of the plasma current. Better ways to drive current non-inductively are being developed using microwaves, radio frequency waves, neutral beams, and the plasma pressure itself. With the MSE diagnostic and the associated computer capabilities, how well these non-inductive current sources are working is known and changes can be made between shots to more effectively operate the tokamak. Ultimately, the calculation of q value at the magnetic axis in real-time will be used to finely control the q during a plasma shot using non-inductive fast-wave or electron cyclotron current drive.

USE OF GENERAL PURPOSE UNIX CYCLES

Several UNIX systems were acquired in the last few years for specific calculations and for use by a limited number of scientists and engineers. In 1994, a large HP UNIX machine (T500) with 3 CPUs was installed and made available to the general user. A HP 735/125 workstation also was installed to specifically do calculations during plasma operations. These two machines (and other UNIX systems on site) are served by an Auspex file server. Approximately 8 GB of user space is available and 20 GB of space is used to store the most active shot data. Several of the most needed computation programs have been ported to the UNIX environment. Thus, the engineer, physicist, and diagnostician now have a greatly increased number of CPU cycles available to perform analysis. During tokamak operating periods, most machines are involved in calculating results between shots. The two above mentioned machines have had a significant effect on the type of calculation which can be made between shots.

As mentioned above, the EFIT equilibrium code is heavily used on the new UNIX systems. The availability of several hundred time slices of equilibrium profiles greatly enhances the ability to understand and modify the plasma shapes. These shapes can be displayed in a movie format and lead to understanding of new phenomena about plasma parameters.

The total evolution of the q profile can be seen from the calculations which can now be done. This allows the physicists to adjust current profile on a shot to shot basis. The poloidal data can be mapped onto the calculated flux surfaces to arrive at electron temperature and density profiles. Two years ago, the physicists were calculating these quantities several weeks after their experiments. The Thomson profile laser diagnostic now can fire up to 8 lasers into the plasma, as frequently as 400 times during shot. This more frequent data results in better time resolution during the lifetime of the plasma, and allows for a better calculation of electron pressure and electron density.

CONCLUSIONS

The new UNIX systems have made it possible to deal with the massive amount of data associated with the operation of a large magnetically confined fusion tokamak device. This includes the collection of experimental data, fast preview of data, and complicated analysis of the data between shots. At a later time, an even more in depth analysis is done utilizing the UNIX CPU cycles. The additional data collected provides more information about what is happening in the tokamak. The analysis which can be done between shots improves the efficiency and effectiveness of operating the DIII-D machine. Thus a very expensive research facility can be operated to maximize the scientific results which are needed to make fusion energy a reality.

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