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Advances in the Operation of the DIII-D Neutral Beam Computer Systems*

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Abstract — The DIII-D neutral beam system routinely provides up to 20 MW of deuterium neutral beam heating in support of experiments on the DIII-D tokamak, and is a critical part of the DIII-D physics experimental program.

The four computer systems previously used to control neutral beam operation and data acquisition were designed and implemented in the late 1970's and used on DIII and DIII-D from 1981 - 1996. By comparison to modern standards, they had become expensive to maintain, slow and cumbersome, making it difficult to implement improvements. Most critical of all, they were not networked computers.

During the 1997 experimental campaign, these systems were replaced with new Unix compliant hardware and, for the most part, commercially available software.

This paper describes operational experience with the new neutral beam computer systems, and new advances made possible by using features not previously available. These include retention and access to historical data, an asynchronously fired "rules" base, and a relatively straightforward programming interface. Methods and principles for extending the availability of data beyond the scope of the operator consoles will be discussed.

INTRODUCTION

Neutral Beam injection systems are used as auxiliary plasma heating for the DIII-D tokamak located at DOE's National Fusion Facility, at General Atomics, San Diego California. The computers which control the neutral beam power supplies and shot sequencing, as well as performing data acquisition and display functions, have recently been upgraded from 20 year old technology [1] to modern hardware using REALIX [2], a variant of the Unix operating system. Further details of this upgrade are described in [3].

Beyond the savings realized from decreased maintenance requirements, ability to choose from current-generation peripheral devices (such as disk drives or other third party products), and beyond the not-insignificant savings in power consumption, there are of course expectations of better, faster performance, and of better reliability and most importantly, that new capability will be added. Having "lived" with the problems inherent in the

old system for a long while, its reliability was in fact still very good. It is only at this point in the upgrade project — after almost five months of operation using the new systems — that we can claim reliability and shot to shot availability for the neutral beam computer systems, is back on par.

The most important difference between the old and new systems is the new computers being "on the net", or networked. The older systems could barely communicate beyond the scope of their own hard wired terminals. This makes a striking difference in the physical connections, each computer has only a power cord, two camac highway connections, and one ethernet connection — period, nicely symbolizing the new-found ease with which data can be shared — whether with the other neutral beam computer, or with the world. Assuming a new role as a National Fusion Facility, it's appropriate if not a requirement that our computers have full connectivity.

From this new vantage point we move forward, to implement the full promise and capability of new systems. The methods used, guiding principles, and some specific examples are described in this paper.

CHALLENGES

In any major system upgrade, the results obtained depend upon walking a line between conserving previously invested effort and hardware and, on the other hand, striving for an 'ideal system' design as might come from a fresh drawing board. For the DIII-D Neutral Beams, the major pre-existing investment was in the I/O — the analog and digital inputs and outputs distributed throughout the power supplies and facility, conforming to the camac standard. Providing the control and acquisition interface between the computers in the control room and the actual neutral beam (NB) hardware, the camac is estimated as an investment of over \$1,000,000.00 for the eight NB systems, made over a period of almost 20 years. Retaining the existing camac hardware considerably narrowed the field of vendors contending for new hardware and software for the control and acquisition systems. Custom development work was requested of Kinetic Systems to produce a VME based CAMAC serial highway driver, for our use and for inclusion in their catalog. Custom work also required for the low-level camac software driver.

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The previous "package" of control, data acquisition, and data display software was developed for General Atomics (and to an extent PPPL) by Lawrence Berkeley Laboratories RTSG (Real Time Systems Group), involving dozens of man-years of effort, with every aspect purpose built. It was clear that to accomplish similar results on short order, there needed to be as much reliance on commercially available software as possible, with the bulk of our work going into the interfaces between them, the description of control screens, and database detailing our physical hardware.

A challenge often presented when systems perform both control and data acquisition, is that of how to accommodate the inevitable list of follow-on tasks involving access to the data, but just slightly beyond the primary focus of the system – the operator console. Needs of neutral beam power supply technicians, control room coordinators, managers and others to access data in a meaningful, and timely manner often gets secondary consideration when a system is being designed. But giving service to this class of user is important, deserving as careful consideration as the needs of the operator. Moreover, the list of tasks, only tends to grow, and that growth can be considered a mark of success for the system. It's important that these needs be considered and accommodated in as generic a manner as possible, so that new requests can be handled easily, rather than each turning into a new, custom software project.

INFRASTRUCTURE

The current arrangement for the new systems with existing hardware is shown in Fig. 1. The computers can be considered as having only three connections – those to each of two camac highways served, and a connection to the EtherNet. The operator's graphics terminals, other distributed terminals, and connections to other machines are accomplished over the network rather than using hard-

wired dedicated graphics systems and terminals previously in use. Since we have been able to eliminate the need for interrupts as classically defined, with the minor exception of such devices as a service-console, these truly are the only connections needed.

Major software elements include low level camac drivers, which in turn interface to the AccessWare™ [3] GUI control package. To sequence shots, perform control logic, and iterate the arming power supplies, an environment for running small "C" routines was developed in-house. An important feature allows multiple copies of the identical routine to be running synchronously or asynchronously, each assuming the identity of one of the four ion sources under control. The AccessWare™ package provides the mechanism for drawing and updating the operator GUI screens, maintains its own database, and a protected database public interface. One interesting and unusual feature of the package is a sub-system known as "rules." Rules register in advance, a dependence on particular database points. In turn, whenever a value "of interest" changes, AccessWare™ executes the corresponding rule. This process is asynchronous, not dependent on the running of a shot-cycle. An example is the recalculation of timing relationships – when an operator changes primary beam timing; this is "noticed" by a rule which then automatically re-aligns timing for the gas, filament and arc power supplies, whether shot procedures are running or not. In practice, severe performance difficulties were encountered, primarily within the commercial GUI package when used in a manner consistent with our needs. During a shot sequence, when four simultaneous procedure "streams" (one for each ion source controlled) were doing very similar operations, bottlenecks were revealed. Two separate instances of a similar problem needed swift remedy. The path for the POPS procedures to access the camac highway, and the data it represents, was through AccessWare. This allows AccessWare to reflect any changes made by POPS in its database and on the

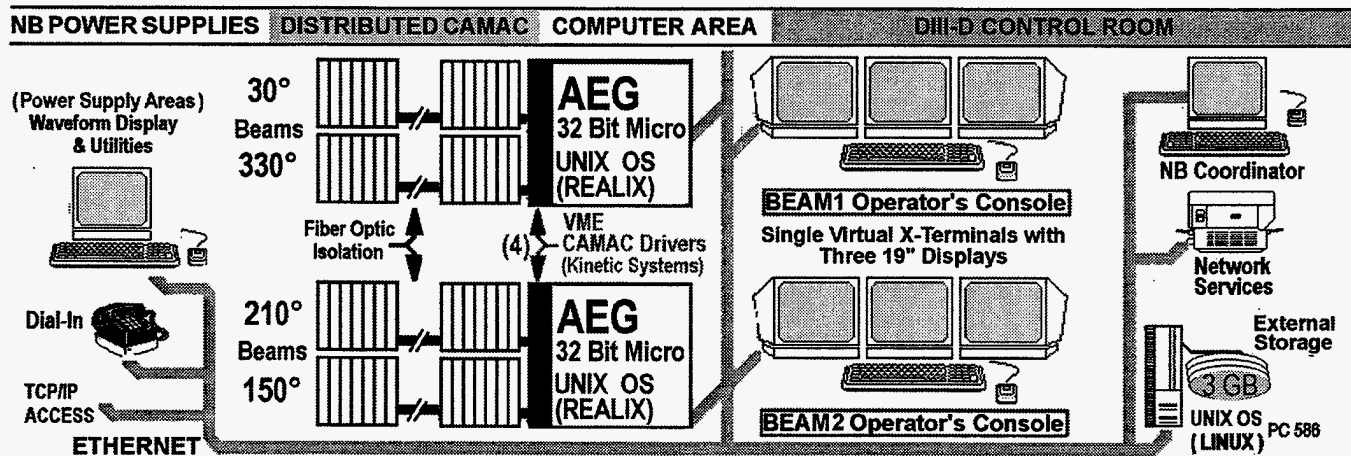


Fig. 1. The hardware and interconnects which comprise the new neutral beam computer systems.

operator screens. During a "GetReady" sequence the "messages" created by the toggling of "momentary" outputs (digital outputs which briefly asserted and then unasserted) were flooding the message queue, causing AccessWare either to ignore and discard some requests or in some cases to "crash", necessitating a relatively lengthy five minute restart procedure with possible loss of shot data. A similar problem was presented by the reading of over 125 thermocouples (600 per beam system computer) with corresponding updates of the AccessWare database and screens. Both problems were solved in a similar manner: Virtually all of the time-critical work and all of the camac highway I/O is now done outside of AccessWare either by POPS procedures or other GA authored "C" code. AccessWare is then updated or informed as to the new status in a non time-critical fashion, at a rate determined not to cause buffer overflows or choking. These measures appear to have resolved our run-time problems, and with the new approach to the thermocouples, have reduced average CPU loading by over 20%.

GUIDING PRINCIPLES

The guiding principle in the interconnection of neutral beam software was to ensure, in so far as was possible, that standard interfaces are presented between the sub-systems. When followed this implies:

- Individual software components may be substituted at a later date without major system-wide ramifications.
- Run time problems can often be localized to an identifiable sub-system, as opposed to being systematic.
- The often daunting task of changes requiring system-wide knowledge can be mitigated by defining new tasks in terms of smaller sub-systems.

For example, to deliver shot-based text data to the neutral beam power supply technicians (who are not running the AccessWare™ GUI) the web-standard HTML (Hyper Text Markup Language) was selected. This implies a wide selection of tools to create new data view templates, and bodes well for the availability of plotting routines and more complicated data visualization. There are also cost benefits to using tools developed for a mass audience, rather than being confined to purpose built or custom packages.

IMPLEMENTATION

Due to concerns about simultaneous control by more than one user, and CPU loading, running multiple copies of the AccessWare GUI control package, specifically in the NB power supply areas is precluded. In normal operation, the local power supply control stations are "observe only" with control switched to the remote computer. In case of power supply problems or other troubleshooting, power

supply technicians need to be able to see the waveforms, operator settings and other details concerning the shot. This category of user may run the in-house plotting package for digitized data (which in turn uses PTDATA, the current DIII-D standard for data description and storage) allowing use of an available X-Terminal. New capability has been added allowing access to archived waveforms from previous shots.

The ability to look at shot logs, summaries and other text based data is being implemented assuming only the ability to use a WWW browser - at present NCSA Mosaic [5]. Capability to plot simple graphical data, such as the relative density of the plasma in the ion source arc chamber, based upon Langmuir probes has been implemented by producing a web-standard .GIF file, which is included in an HTML based summary page.

Using standard tools allows faster development of new displays for use beyond the control room consoles, and enables development assistance by non-programmer personnel. Such populist approaches have brought benefit in the past, and we hope to continue that trend. This additional layer, presenting a standardized interface, is presented in Fig. 2.

Implementation was not without its own special challenges, attributable in part to the original choice of computer platform and vendor. It is unlikely for instance there will ever be a version of the popular unix-based web browser, Netscape™ released or sold as being executable on an AEG REALIX machine!

Fortunately, the origins of the web are in the education and public sector. With source code for the National Center for Supercomputing Application's (NCSA) Mosaic™, we can compile and run Mosaic on the AEG's. A distinct advantage of Mosaic over alternates is its spartan nature. Running even multiple copies has only a small impact on

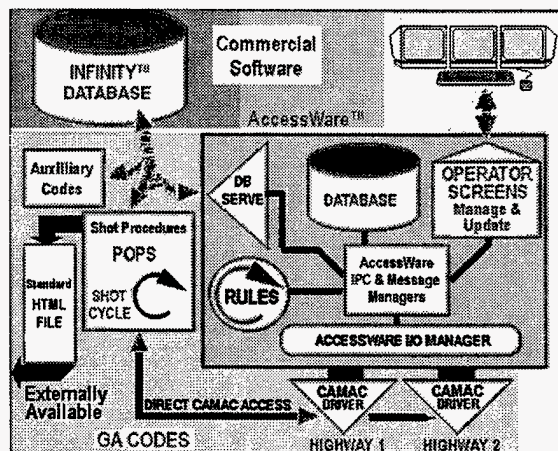


Fig. 2. The combination of commercial and in-house software which together sequence and manage the neutral beam shot cycles and data acquisition.

CPU loading. Another challenge stems from our AEG's status as real-time machines. Policy precludes their running a web server or indeed any service requiring Domain Name Service (the act of looking up and mapping a domain name to an IP address) excluding many network services. The functionality of a Web server is simulated by means of navigational links hard-coded into each HTML document. The Shot Summary "Shot Backward" and "Shot Forward" buttons are not added by a server when the page is served, rather are hard-coded destinations determined at the time of shot. Added indices and top level menus give the collective appearance of a Web server being present. Since there is none, access is currently restricted to those running a web browser local to the AEG's. This may appear a grave limitation, but will soon be easily overcome by copying files to a server as they are created. Using this configuration, practical access limits will be removed.

IMPLICATIONS FOR AUTOMATION

More effort than anticipated was spent restoring the status-quo - the previous capabilities and reliable day to day neutral beam operations. But now new ground is being broken as we move to higher levels of automation and better data access. A layer of standard web-based tools provides the means to produce top level views, and in short order. An example (Fig. 3) is a summary showing the progress of an automatic morning start-up sequence for the ion source filament and arc startup shots.

A template is created using any web-page editor literally in minutes. The page location of variable data is indicated by special tags. A "merge" program joins the standard HTML file with the "data" file generated by our POPS procedure. The resulting HTML file with current data, is then viewable by any browser. One additional feature became important: Upon change of data (for instance after the next shot), the web browser display would be 'stale'

Arc and Filament Auto-Start Master Control					
15° L		15° R		21° L	21° R
Faceted	S1S2	S1S2	S1S2	S1S2	ASYNC
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	S1S2	S1S2	S1S2	S1S2	ASYNC
Started:	Wed Sep 24 09:05:01 1997				
FIL HBQ	6.20 V	6.15 V	6.00 V		
FIL AVG	6.22 V	6.26 V	6.19 V		
Probe 1.0	40.1 KW	36.1 KW	41.1 KW		
Probe 1.2	62.1 KW	57.1 KW	61.1 KW		
Probe 1.4	80.1 KW	78.1 KW	77.1 KW		
Probe 1.6	94.1 KW	WAITING	WAITING		
Status:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Complete	In Progress	LOST PILL		
	08:31:00	40:5	08:16:00		
			SEQUENCE WAITING		

Fig. 3. A sample status page from an automated Arc and Filament shot sequence. The template was quickly developed, demonstrated and approved, using standard WWW tools.

until the operator clicked "ReLoad". Happily, the most recent version of Mosaic for Unix and "X" implements the capability for Mosaic to "listen" for commands on an assigned network socket. A POPS procedure runs at the end of shot, connects at this socket, and informs the browser that new data are available. The browser updates the display without operator intervention or the need to ask "Where are we in this shot sequence?"

FUTURE PLANS

Current efforts focus on seamless production of graphs and data plots on the fly, using web-standard formats. The path is tempered by a commitment to stick with the basics, making few assumptions about the kind of browser or tools used for the client display. In this instance, traditional C code produces standard .GIF files for inclusion and display by the web browser. Using fundamental standards at the interface allows a fuller range of options for the "remote viewing" site, whether across the country, or the Neutral Beam manager's office down the hall. We are also increasing the level of automation in 1) the daily startup of reliable operations, 2) conditioning of an ion source which has been "up to air" for service, and 3) optimizing, conditioning and tuning of an ion source during regular operation. Efforts are in this order of precedence, because our primary obligation is to provide the reliable day-in day-out operation we are known for, rather than to assume new risks in advancing the computational art.

CONCLUSION

Despite challenges presented during development, the new DIII-D neutral beam computers function well, and are reliably executing shot cycles. Using the new infrastructure, progress is now being made towards presenting a uniform external interface for the purposes of inspecting shot based data, reports, and plots. Building on this, the first sequences to automate routine startup and ion source conditioning will be implemented. Near-term plans call for application of similar automation to trimming control parameters and tuning the ion source efficiency, normally performed in the course of day to day ion source operation.

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- [2] REALIX and INFINITY are registered trademarks of AEG/Modcomp Inc., Fort Lauderdale, Florida.
- [3] D. Piglowski, *et al.*, "Use of the accessware interface/database software in the neutral beam control systems used by the DIII-D tokamak," this conference.
- [4] AccessWare is a registered trademark of AccessWare Inc, Houston, Texas.
- [5] MOSAIC is a registered trademark of the Board of Trustees of the University of Illinois.

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