GA–A23829

THE DIII–D MULTIPLE GYROTRON CONTROL SYSTEM

by
D. PONCE, H.K. CHIU, M.B. CONDON, I.A. GORELOV, R.A. LEGG,
and F.W. BAITY, Jr.

APRIL 2002

DISCLAIMER

GA–A23829

THE DIII–D MULTIPLE GYROTRON CONTROL SYSTEM

by
D. PONCE, H.K. CHIU, M.B. CONDON, I.A. GORELOV, R.A. LEGG, and F.W. BAITY, Jr.†

This is a preprint of a paper presented at the 19th IEEE/NPSS Symposium on Fusion Engineering, January 21–25, 2002 in Altantic City, New Jersey and to be published in the *Proceedings.*

†Oak Ridge National Laboratory, Oak Ridge Tennessee

Work supported by
the U.S. Department of Energy under
Contract Nos. DE-AC03-99ER54463 and DE-AC05-00OR22725

GA PROJECT 30033
APRIL 2002

The DIII–D Multiple Gyrotron Control System

D. Ponce, H.K. Chiu, M.B. Condon, I.A. Gorelov, R.A. Legg, and F.W. Baity, Jr.†

General Atomics, P.O. Box 85608, San Diego, California 92186-5608
†Oak Ridge National Laboratory, Oak Ridge, Tennessee

Abstract*-- The recent DIII–D program to upgrade to six 1 MW gyrotrons presented the opportunity to modernize the control and instrumentation systems. The challenge of the system is to allow a small number of operators to control the gyrotrons, which have individual tuning requirements and are sourced from two manufacturers. The main user interface is written in National Instruments' LabVIEW software. Access to PLC functions not available through the LabVIEW interface are provided by Siemens' TISOFT and by Ci Technologies' Citect. The computer control system uses computers connected by ethernet to distribute the control, status, and data functions. The computers which directly interface with the gyrotron system hardware use a rack-mountable and ruggedized compact PCI format. The waveform digitizers and the timing control module, which gates the high voltage power supply, the gyrotron filament boost, and sends the hardware reset and digitizer triggers, are also located in the compact PCI crate. These computers also control hardware responsible for forming the gyrotron pulse shape, programming the sweep coil waveform, setting the waveguide polarizer angles, and detecting asynchronous system events. Many control functions are handled by PLCs which are under computer control. The PLCs are responsible for the vacuum and waveguide systems, access interlocks, filament power supply control, cooling system interlocks, the high voltage power supply interface, gyrotron tank oil interlocks, and launcher mirror control. Control connections to the waveguide launchers at the DIII–D vessel and to the high voltage power supplies are made through patch panels, allowing rapid configuration changes. This paper will provide more detail on the features of the control system, with emphasis on the upgrades.

I. Introduction

The ECH system on DIII–D is in the final stages of an upgrade to 6 MW [1]. This program presented the opportunity to modernize the control and instrumentation systems. Extensive use was made of compact PCI computers and accessories. Signal routing was designed to facilitate reconfiguration. Software underwent a major revision.

During the upgrade, DIII–D acquired two gyrotron systems from the former Tokamak de Varennes program in Quebec, Canada. These systems were integrated into the existing ECH control system [2].

Many aspects of the ECH control system have been covered previously [3]. This discussion will concentrate on subsequent work and planned additions. The topology of the control system is shown in Fig. 1.

II. Pulse and Waveform Control

A. PXI Timing Module

Timing control originates from National Instruments' (NI) PXI-6602 counter/timer modules. These modules supply the fault system reset pulse, digitizer trigger, filament boost pulse, high voltage power supply gate, secondary tetrode gate (if applicable), cathode voltage waveform generator trigger, and, if two gyrotrons share the high voltage power supply, the slave system trigger. There are three on board reference clocks of 80 MHz, 20 MHz, and 100 kHz. Thus, this 32 bit module can generate a 53 s pulse with a resolution of 12.5 ns.

The timing sequence is initiated in one of three ways; manually using a software trigger, continuously using a counter/timer at a preset repetition frequency, or externally by either the DIII–D timing system or by the “master” gyrotron of a master-slave pair sharing a high voltage power supply. Our normal range of continuous repetition frequencies, from 10 Hz to one pulse every 30 min, is easily handled by the PXI-6602.

B. PAL Pulse and Fault Processor

The pulse and fault processor card (PFC), upgraded from a previous design, now features programmable array logic devices (PAL) to provide logic for fault processing and reporting. The PFC receives fault and interlock signals from fault monitors and from the controls PLC (programmable logic controller). Monitored signals include cathode over-current, VacIon over-current, body over-current, waveguide and window arc detectors, and forward and reflected rf.

Fault and interlock signals can cause the PFC to interrupt the high voltage pulse, terminate the pulse, or terminate and fire the high voltage crowbar depending on the consequences of the fault or interlock. If it is necessary to fire the crowbar, this must occur within 10 μs from the time of the fault in order to protect the gyrotron.

C. Arbitrary Waveform Generator

A Wavetek model 395 arbitrary waveform generator provides the reference waveform for the cathode voltage. The model 395 is a versatile instrument, allowing waveform segments to be externally triggered or modulated, and has been in use for several years.

A cathode voltage reference waveform, as implemented, consists of two initial ramp sections, a top section, and a ramp down. The top section can contain a modulation waveform at the beginning, end, or throughout the section. Modulation waveforms are square, triangular, or sinusoidal. Modulation depth to inhibit rf generation depends upon the gyrotron, and ranges from 15% to 30%.

The ability to accept external modulation has recently been added. The system will accept a signal from the DIII–D plasma control computer (PCS) which will modulate the cathode voltage reference waveform within a range set by the

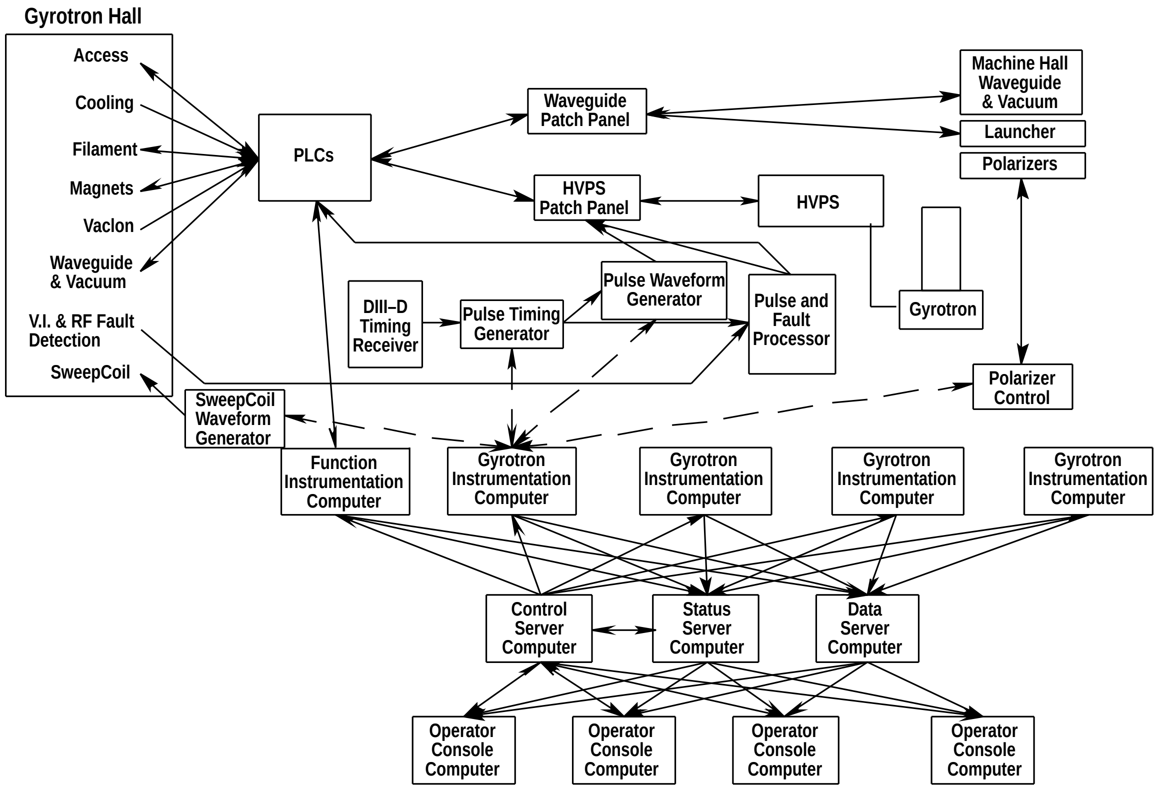

Fig. 1. ECH control system topology.

ECH operator. Thus, ECH or ECCD could be used to control plasma instabilities as determined by the PCS.

III. Magnet and Filament Control

The magnet power supplies are interfaced directly to a control computer, if an isolated GPIB or serial port is available. Otherwise, they are interfaced to the controls PLC using isolated amplifiers, optocouplers, and relays. Any alarm relays are always directed to the controls PLC. These interfaces provide a dc current reference, and monitor current and voltage levels, alarms, and status. The isolation amplifiers used are DIN rail mounted, with an isolation voltage of up to 4 kV and a frequency response of under 1 kHz.

Collector coil magnets usually require a waveform reference to create a sawtooth, sometimes asymmetrical, waveform with a dc offset and a frequency of about 4 Hz. These are created using an arbitrary waveform generator and sent to the magnet power supply through an isolated amplifier. There are two waveform generators currently in use: Wavetek model 395 and Standford Research Systems model DS340. Future systems will use an analog output channel of NI's PXI-6040E multifunction I/O module. The analog input section of this module is currently used for the acquisition of calorimetry signals.

Filament controllers are interfaced with PLCs to provide the filament reference and to read current, voltage, and status. In the most advanced implementation, the PLC controls filament reference ramp up and ramp down, and acts as secondary fault protection to back up the filament controller. The PLC will ramp down the filament reference in response to an operator command or to an interlock or fault signal. The ramp down rate is normally ten times the ramp up rate. If the reference reaches zero before a fault has cleared or if commanded by the operator, it will shut down the filament controller. If the reference reaches zero in response to an interlock, it will wait until the interlock clears and then ramp up to the last operator command.

The filament reference can be boosted during the gyrotron pulse sequence to compensate for cathode emission induced cooling. The PLC outputs both a filament idle and boost reference. A CMOS switch, controlled by a pulse from the gyrotron timing module, sends the selected reference on to the filament controller. For a ten second gyrotron pulse, the filament current will be boosted by 14% for five seconds prior to the pulse.

IV. Waveguide Control

A. Launcher

The P1999 and P2001 launchers, developed by Princeton Plasma Physics Laboratory, allow for remote control of the launch mirror angles. A PLC, equipped with a high speed quadrature counter with programmable outputs, positions the mirrors in response to operator commands given through a software panel written in NI's LabVIEW. The launch mirrors are driven by air motors and have encoders on the actuator arms.

B. Polarizers

Each waveguide line uses two remotely controlled, rotating grooved mirrors to control the polarization delivered to the tokamak. The polarizer stages were upgraded to work with Newark's ESP300 motion controller. This combination allows for automatic stage identification, automatic setup of motion parameters, and automatic homing. The controller includes an I/O port which can be controlled programmably. This is being used to set a hardware interlock to inhibit gyrotron operation while the stage is in motion.

C. Switch, Valve and Vacuum Control

Waveguide switches and valves are operated by the controls PLC, based upon input from the Granville-Phillips vacuum gauge controllers. Each waveguide line has a waveguide switch to direct the rf beam to the tokamak or to a dummy load. A waveguide valve is used to isolate the gyrotron from the tokamak when rf power isn't required. Vacuum valves are used to automatically isolate the turbo pumps from the waveguide if the waveguide is inadvertently vented.

V. DATA ACQUISITION

A. PXI Multi-I/O Modules

Data is acquired at three speeds. Gyrotron waveform data, such as cathode current and voltage, is collected using an NI PXI-6070E multifunction I/O card with an SC-2040 simultaneous sample and hold card on the front end. Together, these cards provide 8 channels of 12 bit simultaneously collected data, at up to 71 kS/s (kilo-samples per second) each.

Fault data is collected using two NI PXI 5102 2-channel digital oscilloscope cards. These cards can acquire 8 bit data at 20 MS/s for 16.5 ms simultaneously. Fault events, in which the high voltage crowbar is fired, should be over in 10 µs. In future systems, these cards will be replaced with one NI PXI-6115 10 MS/s, 12-bit, 4 channel, simultaneously sampling card. The 16 million sample buffer can store 400 ms of data.

Calorimetry data, consisting of coolant differential temperature and flow rate, is collected using an NI PXI-6040E card. It is used on single ended signals, and so 16 channels are available at 15 kS/s each with 12 bit resolution. The actual data rate used for most of these signals is 10 S/s.

B. Near Real-Time Redistribution

Waveform data for a particular gyrotron, consisting of cathode voltage and current, rf detector signals, and fast diagnostic signals, will be collected and routed to the operator to give a near real-time display. The PXI-6070E data acquisition card can send data over the local PXI crate's PCI bus to disk at up to 1.25 MS/s, or 156 kS/s per 8 channels. Each gyrotron instrumentation computer has a dedicated full duplex fast Ethernet line to the ECH data server. At a peak speed of 100 Mb/s, the Ethernet line can transfer 16 bit data at a rate of 780 kS/s per 8 channels. On the data server, the 132 MB/s PCI bus sends the data to two 80 MB/s Ultra 2 Wide LVD SCSI buses. Servicing eight gyrotron systems, the PCI bus can handle 1 MS/s per channel peak. Each gyrotron system has a dedicated LVD SCSI hard drive on the server, so that data can be written contiguously as it is received. The drives are 9.1 GB, 10 K RPM Seagate Cheetahs, with a transfer rate of 152–231 Mb/s, which equates to 1.1–1.8 MS/s per channel. The data will be stored on these disks for near term use and archived onto CD-R or DVD-R.

The data will be transferred to the operators over a fast Ethernet network. If three users require all 64 channels, the maximum transfer rate, assuming minimal network traffic, will be 97 kS/s per channel. If the operator is limited to a 10 kS/s per channel stream, a more practical rate, nearly two-tenths of a second of data could be viewed at full resolution on a 1920 pixel wide display. A two second pulse could be viewed with a zoom of 10× available. A ten second pulse could be viewed with a zoom of 50× available.

VI. CONTROL SOFTWARE

A. Servers

Four programs provide control system services. These are the control, status, data, and external servers. The control server accepts commands from the operator's control client screen and applies any rules or limits. It then logs the command and forwards it to the appropriate instrumentation computer. The status server obtains current settings and status from the instrumentation computers. The information is organized and sent to operator's status client screens. The data server, which is in development, will provide operator's data client screens with near real-time and archived waveforms. The external server, which is also in development, will allow status and data to be viewed from the external DIII–D network and the Internet. It will also allow, at the operator's discretion, for pulse timing commands to be accepted from the DIII–D network.

The control, status, and data servers and their clients are written in NI's LabVIEW. The external server will be written in a combination of LabVIEW and Research Systems' IDL.

B. Operator Interfaces

The operator interfaces are clients to the server programs. The control client allows the operator to enter commands and displays the current set of commands as understood by the command server. Unless restricted, the operator is able to command one or more of the gyrotrons from any of the internally networked computers running the command client.

The status client provides the operator with interlock, fault, and pulse status and with analog readouts. Interlock status is formatted to help the operator complete the interlock chains. These screens are also available anywhere on the internal network.

The operator is also able to view data on the PLCs without using the LabVIEW interfaces. The controls and the launcher PLCs can be interrogated using Siemen's TISOFT. The former TdeV PLCs are interfaced with Siemen's APT or with Ci Technologies' Citect. TISOFT allows the operator to view the PLC ladder logic code with interlock status and analog values overlaid on the code diagram. Citect provides an operator interface for the TdeV high voltage regulators and gyrotron subsystems. Operators can set operating points, monitor interlocks, and review alarms. APT is used to program the TdeV PLC and to set alarm points.

VII. Hardware Architecture

A. Distributed Computing Functions

Computing functions are distributed among several computers to provide robustness though redundancy and adequate processor capacity. There are three classes of computers as implemented: servers, operator's consoles, and instrumentation controllers. The servers run the control system server applications, and are also minimally used as operator's consoles and as general workstations. The operator's consoles run the operator client applications. They are also used as general workstations. An auxiliary operator console runs the controls PLC driver application.

The instrumentation computers communicate directly with system hardware. They control the timing hardware, waveform generators, polarizer controllers, waveform digitizers, and, in some situations, PLCs and magnet controllers. There is generally one instrumentation computer per gyrotron, consisting of a NI PXI-8156B. These computers are in a compact PCI embedded format, and are housed in a NI PXI-1000 crate, which provides a ruggedized environment. The PXI digitizer and counter/timer modules are also housed in this crate.

With the exception of the external server, ECH computers run on an internal network. The servers and main operator's consoles are connected with a fast Ethernet switch. The instrumentation computers are connected through Ethernet hubs to the servers. They also have a direct fast Ethernet crossover connection to the data server to transfer near real-time waveform data.

LabVIEW applications communicate to each other using the TCP/IP protocol. The NetBEUI protocol is used for Microsoft Window networking functions, including file sharing.

B. Patch Panels

The hardware design for the ECH Upgrade to 6 MW program anticipated the need to facilitate system reconfigurations, and included several patch panels. There are major patch panels to handle gyrotron to launcher and gyrotron to high voltage power supply assignments. These panels include identification bits in multi-pin cables so that the interlock system can verify that the panel is configured as specified by the operator.

There are also minor patch panels which are used to send waveform signals to digitizers and oscilloscopes, and to route trigger signals and pulse commands.

VIII. Conclusions

The DIII–D multiple gyrotron control system, although not fully implemented, was used successfully to commission two new CPI gyrotrons and to resurrect two Gycom gyrotrons acquired from TdeV. The system was used during the year 2001 DIII–D experimental campaign and helped ECH to obtain a high level of reliability. The patch panels displayed their value during system reconfigurations.

Acknowledgment

Work supported by U.S. Department of Energy under Contracts DE-AC03-99ER54463 and DE-AC05-00OR22725.

References

[1] W.P. Cary, R.W. Callis, J.M. Lohr, D. Ponce, R.A. Legg, "The upgrade of the DIII–D 110 GHz ECH system to 6 MW," Proc. 18th IEEE/NPSS Symp. on Fusion Engineering, Albuquerue, New Mexico, (Institute of Electrical and Electronics Engineers, Inc., Piscataway, New Jersey, 1999) p. 190 (1999).

[2] R. Cool, et al., "Control and protection system for the 110 GHz ECRH system on the TdeV tokamak," Proc. 17th IEEE/NPSS Symp. on Fusion Engineering, San Diego, California, Vol. 1 (Institute of Electrical and Electronics Engineers, Inc., Piscataway, New Jersey), p. 527 (1997).

[3] D. Ponce, J. Lohr, J.F. Tooker, W.P. Cary, and T.E. Harris, "The DIII–D ECH multiple gyrotron control system," Proc. 17th IEEE/NPSS Symp. on Fusion Engineering, San Diego, California, Vol. 1 (Institute of Electrical and Electronics Engineers, Inc., Piscataway, New Jersey), p. 552 (1997).