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TIMING SYSTEM FOR NEUTRAL BEAM INJECTION ON THE DIII-D TOKAMAK

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Abstract: Eight neutral beam (NB) long pulse sources mounted on four beamlines are in use on the DIII-D tokamak, a magnetic confinement fusion experiment at General Atomics. The main purpose of NB injection is to heat the bulk plasma with high energy injected neutral particles which undergo ionizing collisions with plasma ions and electrons. NB injection is also used as a diagnostic tool for charge exchange recombination spectrometry to determine ion temperatures and rotation velocities and for neutral particle charge exchange spectrometry to determine spatial distributions of beam ions.

This paper describes recent modifications to the DIII-D central timing system hardware and software to allow more flexible and complex timing waveforms than previously available to control NB injection. In the past, for each plasma discharge, the start time and the pulse duration for each NB source could be set. The new NB timing system allows the experimental session leader to specify more than one pulse for each NB source to make efficient use of multiple physics experiments in a single discharge. Also, pulse trains with programmable duty cycles can be independently specified for each NB source to make NB injection a more useful diagnostic tool. Experimental results using features of the new NB timing system are presented.

Introduction

The DIII-D tokamak is a magnetic confinement fusion experiment at General Atomics. A DIII-D tokamak discharge occurs when gas is injected into the DIII-D vacuum vessel and is ionized into a plasma. An experimental run consists of tokamak discharges which last several seconds and are repeated every 10 to 15 minutes. Before each discharge, control and data acquisition equipment is initialized. During each discharge, in real-time, data is collected by CAMAC digitizers, scalars, and other modules. Currently, DIII-D collects 40 to 50 Mbytes of data per discharge.

This paper describes recent modifications to the DIII-D timing system [1] hardware and software to allow more flexible and complex timing waveforms than previously available to control neutral beam (NB) injection. Eight neutral beam long pulse sources mounted on four beamlines provide up to 2.5 MW of neutral beam power each (20 MW total) in deuterium discharges with ion energies up to 80 keV. NB ion source and power supply hardware allow NB injection in a 30 second window starting from NB pulse initiation. Heat load considerations restrict the cumulative on time for each NB source to 5 seconds in that window [2].

Section 1 is an overview of the DIII-D timing system. Section 2 describes the hardware and software of the new NB timing system. Section 3 describes experimental results taking advantage of the features of the new NB timing system and includes a short summary.

Section 1 — Central Timing System Overview

During experimental runs the DIII-D timing system coordinates the tokamak and its associated power systems, the

auxiliary heating systems including the NB injection system, and diagnostics. The DIII-D timing system consists of trigger and clock subsystems and the NB timing subsystem.

The trigger subsystem synchronizes control and data acquisition for the experiment. The clock subsystem is a centralized source of pulses for data acquisition equipment. The NB timing subsystem provides an independent waveform for each NB source to modulate the injection of neutral particles during a tokamak discharge.

Physics operators are able to inspect and easily change timing parameters such as trigger times and clock frequencies and NB source timing waveforms between discharges without compromising the consistency between hardware configurations and software descriptions.

Any and all timing parameter changes are automatically and transparently propagated throughout the data acquisition and control database and the central experimental database. Database retrieval software interprets complicated timing information for a user accessing data from the experimental database.

Section 2 — Neutral Beam Timing System

Design Criteria

With the advent of the long pulse NB sources and improved diagnostics and plasma control at DIII-D, upgrading the NB timing system was needed to meet the requirements of physics experiments. The new NB timing system was designed and implemented with minimal impact on the existing timing system and NB control system.

In the past only the start time and the pulse duration for each NB source could be set. Figure 1(a) shows the general waveform which can be specified for each NB source with the new timing system. The waveform consists of three segments specified by a total of eight parameters. The "first pulse" and "final pulse" segments are each parameterized by a start time and duration. The "pulse train" segment is defined by the number-of-pulses, a start time, and on and off durations (constant duty cycle.) Zero duration for "first pulse" or "final pulse" will suppress that segment of the waveform. Zero number-of-pulses for the "pulse train" will suppress that segment.

Hardware

The timing waveforms are generated by a Jorway 221-1 sequence generator CAMAC module connected to a Jorway 222 buffer driver. Eight of the twelve available outputs are used, one to control each NB source.

The programmed waveforms interrupt or modulate a permit gate shown in Fig. 1(b) generated by the NB control system. The duration of the permit gate may be restricted by the NB control system software or may be interrupted by external interlock signals during a discharge. If a permit gate signal is off then

Fig. 1. DIII-D neutral beam timing system waveforms: (a) general NB modulation waveform (independent waveform for each NB source), (b) relationship between NB modulation waveform and permit gate.

that NB source will not inject regardless of the timing system sequence generator output.

The DIII-D timing system master 1 MHz clock is used to clock the sequence generator and a DIII-D synchronous trigger starts the sequence generator each discharge. This ensures that NB modulation is synchronized with other DIII-D subsystems. Digitizers which are part of the standard data acquisition system acquire actual NB source current and voltage signals.

Software

Physics operators use an interactive timing system program to display and modify all DIII-D timing parameters between discharges. Figure 2 is a typical graphical display showing the timing waveform for each NB source, the aggregate timing waveform of all the NB sources, and other timing system information.

A spreadsheet-like user interface is used to specify the eight parameters for each of eight NB sources to define the eight independent NB source timing waveforms. Whenever a change is made and validated the program writes these 64 timing parameters to a file, calculates an overall start and duration shown in Fig. 1(b) for each NB source based on each entire waveform, and writes these (16 in total) parameters to another file.

This second file contains information already available in the larger file containing the full set of NB timing parameters. The smaller file is maintained to simulate the behavior of the old NB timing system thus requiring no software changes on the NB control computer for the NB timing system upgrade. The smaller file is read by the NB control computer during the initialization phase of each discharge. When the NB system is on-line the permit gate duration is set to the minimum of the requested overall duration and the maximum NB duration allowed by the NB control system. As a safety precaution the maximum allowed duration for each NB source is set manually by the NB operator.

A separate code which executes during the initialization phase of each discharge on the central data acquisition computer reads the file containing the full set of 64 NB timing parameters.

This code translates the eight parameters per source into the set point and channel select arrays expected by the Jorway 221-1 sequence generator. The code loads and arms the sequence generator in preparation for the upcoming discharge.

Section 3 — Experimental Results and Summary

Charge Exchange Recombination Spectroscopy

A multichord spectrometer system installed on the DIII-D tokamak [3] measures ion temperature and plasma rotation velocities by the techniques of charge exchange recombination (CER) spectroscopy [4]. CER spectroscopy obtains the Doppler width and Doppler shift of emission lines from the plasma interior produced when energetic NB hydrogen atoms transfer an electron to a fully ionized low-Z impurity ion (typically He II or C VI) in the plasma.

The desired CER signal comes from the region where the spectrometer view chord intersects the neutral beam. However,

Fig. 2. DIII-D neutral beam timing interactive display.

the spectrometer also acquires signal from interfering spectral lines located elsewhere along its line of sight. Subtracting a background spectrum from a signal spectrum corrects for this interference and yields a single Gaussian peak in wavelength space which can be fit easily and accurately. This technique's success requires that the background vary little during the time that the signal and background spectra are obtained. NB modulation is crucial to minimize this variation by obtaining signal and background spectra closely spaced in time and has proved to be very valuable in analyzing data with poor signal to background ratios.

Figure 3 illustrates the benefits of using background subtraction in CER data analysis. The total spectrum (signal plus background) is acquired during a 10 ms window while NB injection is on. The background spectrum is acquired in the preceding 10 ms window where NB injection is off. After background subtraction the spectrum can be fitted by a single Gaussian. Without background subtraction the fit would require three Gaussians and corrections for the emission lines on the wings of the peak.

Neutral Particle Spectroscopy

An $E \parallel B$ neutral particle spectrometer installed on the DIII-D tokamak measures the spatial distribution of NB ions. Its sightline is scanned discharge to discharge across a neutral beam in the plasma. NB modulation allows the beam signal to be differentiated from the plasma background [5].

Summary

The new neutral beam timing system was developed to take advantage of the upgraded long pulse NB sources on the DIII-D fusion tokamak experiment at General Atomics. It meets experimental physics and diagnostic requirements by allowing complex timing waveforms which control NB injection to be easily specified and inspected between plasma discharges.

Acknowledgment

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Jan Gilgallon added modulation capability to the NB power supply system hardware.

Fig. 3. DIII-D CER data illustrating benefits of background subtraction.

Paul Thurgood developed the spreadsheet-like user interface routines used by the author's interactive timing system code.

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