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The NSTX-U Digital Coil Protection System Autotester

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Abstract— **Included in the Upgrade to NSTX at Princeton University's Plasma Physics Laboratory, is the development of a Digital Coil Protection System (DCPS). This real-time system is the primary protection for the machine coils and structure of the NSTX-U vessel. A requirement for a means to thoroughly test the DCPS birthed the Digital Coil Protection System Autotester (AT). From its inception in May of 2013, the purpose of the DCPS Autotester system was to provide the user a means by which to send a pre-configured set of waveforms to the DCPS for the purpose of testing the functionality of the system. The output data stream consists of 64 analog outputs and 32 digital outputs at a rate of 5k samples per second. The AT monitors 32 digital inputs coming back from the real-time system. It logs all data sent to the system and the outputs from the system during each test cycle. The AT application, written using National Instruments LabVIEW 2013, can be run stand-alone or synchronized with the central NSTX-U Facility Clock (cycle). The AT also provides a continuous sample clock, which is required by the real-time system, whether or not the Autotester software is running.**

Although the Autotester was developed for the single purpose of certifying the DCPS system, it has grown in purpose. Recently, it has been used to test and validate the NSTX-U Power Supply Real Time Control system. Plans call for using it to verify new systems such as the Plasma Current Calculator and Permissive Generator which are relevant to Day 1 NSTX-U operations.

Keywords—diagnostics; data acquisitions; plasma control systems

I. INTRODUCTION

The NSTX Upgrade (NSTX-U) experimental device has an operating space that is both larger and more complex than that of the original NSTX [1]. An upgrade to the existing protection systems and methodology was required to allow for both safe and effective use. The Digital Coil Protection System (DCPS) provides the primary protection for the machine coils and structure. One of the requirements states that the DCPS will employ regression testing for system validation in response to system upgrades, modifications, and bug fixes [2]. This has evolved into the DCPS Autotester (AT). The AT is used to test waveforms generated to produce specific scenarios, generate faults at specified times, allow for examination of output from calculations known as algorithms, and verify that faults occur for the proper reason.

The Autotester is designed to simulate the behavior of the NSTX-U device, thus it must supply all input streams that the DCPS receives during NSTX operations. The inputs that the AT must simulate are:

- Redundant scaled analog versions of the poloidal and toroidal magnet currents (28 total)
- Redundant scaled analog plasma current (2 total)
- Digital interlock status bits
- Reset bits to reset faulted DCPS
- Experimental window trigger inputs
- Auto-sensed mode bits for OPS/TEST mode [2]

II. OPERATIONAL OVERVIEW

A hardware interface allows for switching DCPS modes between "Real World", i.e. NSTX Operations, and the "Autotester" environment. This is done through a pair of keycards, one for each configuration, inserted into the hardware interface chassis. When DCPS runs while connected to the Autotester via this hardware interface, no experimental power is applied to the NSTX-U device.

The AT system is completely autonomous. It does not require any inputs from the "real world" other than the DCPS outputs and the current shot number obtained from MDSPlus. The AT has no way of knowing whether or not it is connected to and therefore driving DCPS.

The AT has two modes of operation: 1) synchronous with the NSTX clock cycle events – the AT receives start of cycle from the NSTX clock, 2) asynchronous, or independent of the NSTX clock cycle; the user controls the start of clock trigger event. AT users include test engineers and system engineers.

III. AUTOTESTER SYSTEM COMPONENTS

A. Hardware

The Autotester hardware is a 4U rack mounted industrial computer running the Windows 7 64-bit operating system with

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National Instruments (NI) PCI and PCIexpress devices for sample clock, analog output generation and digital I/O [3]. The devices are:

- NI PCI-6601 – timing and digital I/O
- NI PCI-6723 (2) – analog output (AO), 13-bit, 32 channels, up to 45 kS/s
- NI PCIe-6535B (2) – digital I/O (DIO), 24 channels, 10MHz

The devices are connected by a Real Time System Integration Bus (RTSI) for synchronization. The computer is located in the Field Coil Power Conversion (FCPC) Junction Area (JA) on D-Site, and is on a control systems network. Users log in via Remote Desktop Connection.

B. *Software*

The Autotester is a National Instruments (NI) LabVIEW 2013 (32-bit) program using NI's latest data acquisition drivers, known as NI-DAQmx, for configuring and controlling the devices. The devices are configured for hardware-timed, buffered sample generation: finite mode for the shot cycle, continuous mode for in-between shots. Via the Graphical User Interface (GUI), the user sets up waveforms for the coil currents and plasma current, selects clock event times for a shot cycle, sets up inputs to simulate NSTX-U support systems such as Pulse Duration and Period Timer (PDP) Window and Water Systems Programmable Logic Controllers (PLC). The user can setup inputs to simulate faults at specific times and/or commands to override faults or reset states. For a test shot cycle, the Autotester loads the devices with waveforms and setup info and starts analog and digital generation for the period from Start of Clock (SOC) to End of Pulse (EOP). At the end of the shot cycle, the Autotester stores the acquired data and the entirety of the setup data into an MDSPlus tree. The AT user runs a stand alone executable version of the LabVIEW program which is built using NI Application Builder.

IV. TIMING AND SYNCHRONIZATION

A. *The Sample Clock*

The timing of clock events and the synchronization of inputs to DCPS is of utmost importance. DCPS is required to be actively protecting at all times, even between shot cycles. Thus, while DCPS is connected via the hardware interface, the AT supplies a continuous sample clock, whether or not a user is running the AT application. A dedicated Sample Clock LabVIEW VI, installed as a Windows Service on the AT computer, supplies the sample clock using the NI 6601 device. The Sample Clock VI sends the signal to DCPS via a PFI terminal, and communicates with AT application via the RTSI bus. A 1MHz external clock (from the Facility clock used for the "Real World" configuration) supplies the time base for the 6601 counter. This keeps the AT and the DCPS computer in sync with the Facility Clock throughout the minutes-long shot cycle. The Sample Clock VI runs when the computer is powered up, whether or not a user has logged in.

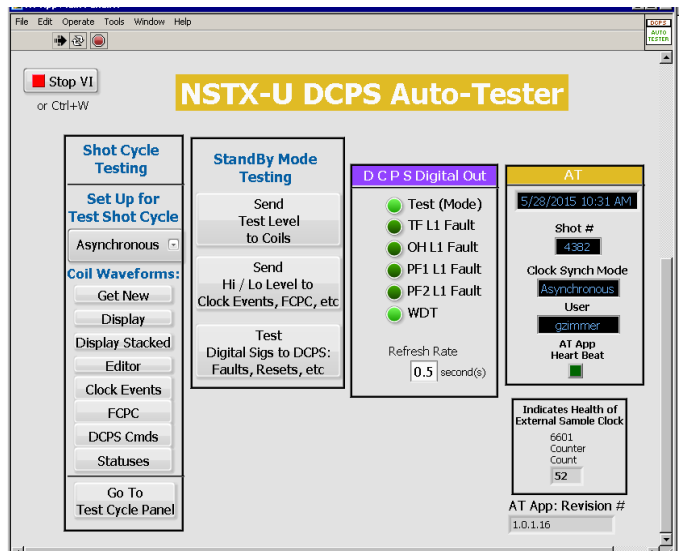
B. *Triggering*

Triggering is also of importance in synchronization of waveform generation and digital input/output. Analog Output device #1 is triggered at Start of Clock. The other 3 devices are set to trigger from device #1 via the RTSI bus. In synchronous mode, the Start of Clock signal is from the Facility clock via a PFI terminal. In asynchronous, the AT application generates the trigger is internally.

V. THE GRAPHICAL USER INTERFACE

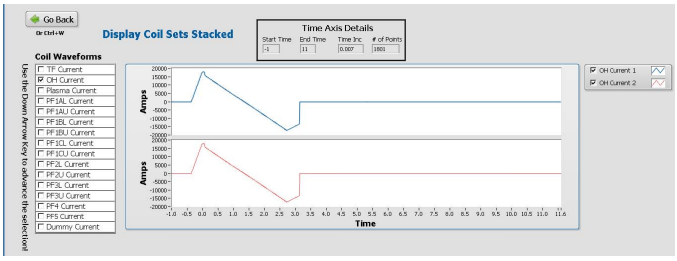
A. *The AT Main Panel*

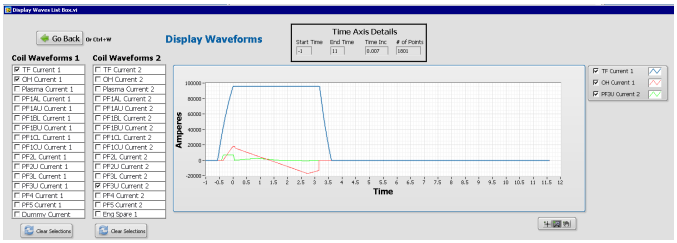
The LabVIEW application provides multiple graphical panels to allow the user to easily set up the data to be generated during a test shot cycle.



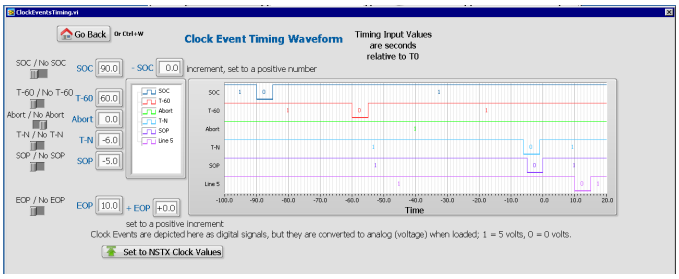
B. *Setting Up the Data for a Test cycle*

The AT user reads in coil waveforms from pre-defined text files. The user can choose distinct files for each coil set. Separate panels allow the display of the waveforms in overlay and stacked fashion.





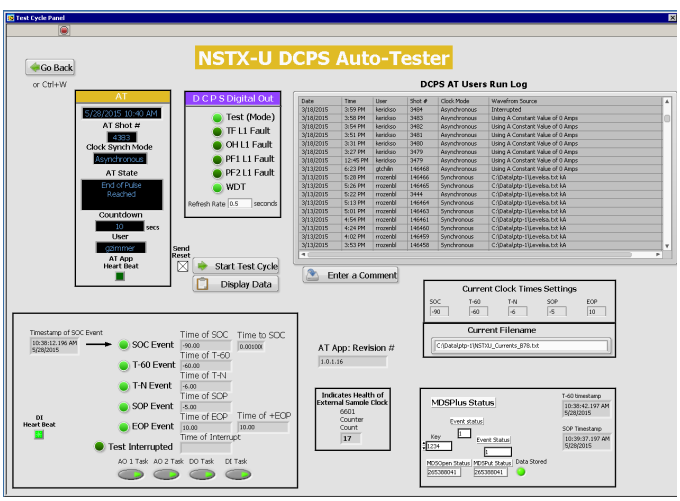
The AT is responsible for sending to DCPS the clock cycle events “Start of Clock” (SOC), “T minus 60” (TM60), “T minus N” (T-N), “Start of Pulse” (SOP), “End of Pulse” (EOP) and Abort (normally in the no abort state). These are represented as 5 volt / falling edge to zero (active low) waveforms on 6 analog channels.



There are similar panels for setting up the FCPC Events and the Fault and Reset Commands. As the user enters new values, the plot updates, providing a visual representation of the signal waveform.

C. *The Test Cycle Panel*

The user initiates a test cycle via the Test Cycle Panel. The panel monitors digital data received from DCPS (mode bits, fault statuses), monitors progression of clock events during the cycle, and displays data at the end of the cycle.



VI. SIGNAL GENERATION

The coil waveforms are read in from text files that created in other applications. The files contain values for coil currents and plasma current as a function of time. The data typically specify 1800 time-value pairs that represent a time span from -1 to 11 at a time increment of 7 milliseconds. The Autotester software extends the end points to span SOC to EOP, and interpolates the values to the desired time base of 200 microseconds. It also applies the proper scale factors, converting amps to volts.

During the setup process, the AT App displays the values for the clock events in a binary form with half second granularity. For the test cycle, the AT app converts the values to 0 volts / 5 volts, and interpolates to the desired time base. In a similar fashion, the AT app prepares analog signals for PDP Allow / Inhibit, Water Permissive, Flow, High Temperature, HSC Power OK, and digital signals for fault statuses and reset commands.

Upon launch, the AT application loads default values for all device channels and configures the devices for continuous, buffered generation. When the user clicks the ‘Start Test Cycle’ button, the interpolated waveforms are loaded and the devices are configured for finite, buffered generation. At EOP, the generation of analog and digital data ends, and the system returns to continuous generation of default values. The interpolated waveforms are stored in MDSPlus files.

VII. TESTING METHODOLOGY

The Autotester has been used numerous times during the ongoing pre-operational testing phase of NSTX-U. Testing is conducted according to a Pre-Operational Test Procedure (PTP) which verifies the following aspects of DCPS operation :

- DCPS input data stream and output data stream and data calibration factors
- DCPS timing and data acquisition
- Proper interpretation of NSTX-U shot sequence signals
- DCPS algorithms, Level 1 Fault response, and Watch Dog Timer response

The PTP exercises the DCPS by

- Checking response to overcurrent levels in the coils
- Utilizing baseline subtraction
- Insuring that the redundant input currents do not differ by more than a specified tolerance
- Conducting auctioneering
- Demonstrating response to an Abort event
- Demonstrating response to clock events occurring out of order

Auctioneering is a method of selecting between redundant current measurements, the highest current being used for DCPS calculations [4].

The test procedure involves 122 test shot cycles, and tests 5 types of algorithms, with over 100 distinct instances in total. It has been ‘officially’ completed five times during the development of the DCPS.

VIII. CONCLUSION

The Autotester was installed in the Junction Area in the summer of 2014. DCPS PTP testing using the AT has been completed in preparation for DCPS to be used during Rectifier Dummy Load Testing. The JA AT is maintained in an operational state to support testing of future DCPS Software

modifications and upgrades. An identical Autotester system was installed in the Fusion Computer Center (FCC) last December for testing of NSTX-U Power Control System (PCS) and Power Supply Real-Time Controller (PSRTC). The FCC AT is also used to test software revisions to DCPS prior to deployment. The JA AT has been modified to support running PTPs for other new systems such as the Plasma Current Calculator and Permissive Generator. New data acquisition, control and protection systems will be designed to accommodate the JA AT for PTPs.

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