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DESIGN AND IMPLEMENTATION OF A CONTROL AND DATA ACQUISITION SYSTEM FOR PELLET INJECTORS*

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Abstract: A stand-alone control and data acquisition system for pellet injectors has been designed and implemented to support pellet injector development at Oak Ridge National Laboratory (ORNL) and to enable ORNL pellet injectors to be installed on various fusion experimental devices. The stand-alone system permits LOCAL operation of the injector from a nearby panel and REMOTE operation from the experiment control room. Major components of the system are (1) an Allen-Bradley PLC 2/30 programmable controller, (2) a VAX minicomputer, and (3) a CAMAC serial highway interface. The programmable logic controller (PLC) is used to perform all control functions of the injector. In LOCAL, the operator interface is provided by an intelligent panel system that has a keypad and pushbutton module programmed from the PLC. In REMOTE, the operator interfaces via a VAX-based color graphics display and uses a trackball and keyboard to issue commands. Communications between the remote and local controls and to the fusion experiment supervisory system are via the CAMAC highway. The VAX archives transient data from pellet shots and trend data acquired from the PLC. Details of the hardware and software design and the operation of the system are presented in this paper.

1. Introduction

The development of pneumatic pellet injectors for fueling plasma fusion devices has been under way at ORNL since 1976 [1]. Pellet injection experiments have been carried out on tokamaks at ORNL and other laboratories with minimal controls on the injection system. With the current generation of plasma devices it is necessary both to have remote control of all aspects of the pellet injector's operation and to record important pellet parameters such as speed and size. Independent pellet injector controls are also desirable so that the injector system can be fully tested before installation on a particular plasma device.

A control and data acquisition system has been designed at ORNL that can be used with ORNL pellet injectors on any tokamak device without major modification. The system has been implemented on the Repeating Pneumatic Injector (RPI) and installed on the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory (PPPL). Additional implementations are currently under development for the Deuterium Pellet Injector (DPI) [2,3] for installation on TFTR and for new pellet injectors to be installed on the Joint European Torus (JET) and Tore Supra devices. The system allows for complete checkout of the pellet injector, including remote operation and data acquisition while at ORNL before installation on the tokamak device.

2. Configuration

A block diagram of the control and data acquisition system as installed on TFTR is shown in Fig. 1. The system uses an Allen-Bradley PLC 2/30 programmable controller to perform all of the control functions except the actual firing of the pellets, which is triggered from the timing system of the tokamak. The PLC is interfaced to a VAX minicomputer for remote operation through a CAMAC RS-232 module. Local operation of the injector is provided by an intelligent panel system that has a keypad and lighted pushbutton module programmed from the PLC. The VAX has a CAMAC byte serial highway interface that is used for color graphics status displays, data acquisition from transient recorders, and the communications link with the PLC. The CAMAC crates installed with the local controls are linked via fiber-optic U-port adapters to the remote crate at the VAX.

The CAMAC interface allows for simple interconnection to the timing and control system of the tokamak upon which the pellet injector is installed. A pellet firing sequencer, part of the timing and control system of the tokamak, is loaded with firing times from the VAX and triggered by the timing pulses of the machine. The outputs of the firing sequencer activate power supplies that energize fast-operating solenoid valves to fire the pellets and, simultaneously, trigger the transient recorders for pellet diagnostic data acquisition.

3. Local Controls

The local controls are the actual control elements that interface directly to the pellet injector and consist of the PLC and its associated intelligent panel system, the cryogenic temperature controllers, and pressure instrumentation. Hardwired interlocks are wired in series with some of the PLC outputs to enable protection of the tokamak device and to meet the requirements of the tokamak control system. Additional control panels are provided to allow direct operation of the pellet injector valves in the event that the PLC is unavailable.

The PLC is an Allen-Bradley PLC 2/30 with 8000 bytes of RAM memory and five I/O racks that contain analog, discrete, and RS-232 I/O modules. The PLC program, written in ladder logic, is structured around the various functions performed: remote communications with the VAX, intelligent panel system, remote device communications, and the handling of the analog and discrete I/O.

The cryogenic temperature controllers are Lakeshore model DRC-82C's which can use either silicon diodes or carbon glass resistors as the resistive temperature sensing element. The controllers have internal proportional, integral, derivative (PID) control that may be programmed from the front panel or from an IEEE-488 interface. The cryogenic system is sufficiently stable that the PID parameters may be set locally, so that the only interaction of the controllers with the PLC consists of receiving setpoints and transmitting the current temperature. The PLC can communicate with up to 15 temperature controllers through a 1771-DA ASCII I/O module and an RS-232 to IEEE-488 converter.

The intelligent panel is a microprocessor controlled panel system from Allen-Bradley that can be configured with a variety of panel modules. A 1771-IM1 I/O module on the PLC is interfaced to the intelligent panel with an RS-232 cable and allows all of the panels to be programmed through the PLC. The pellet injector

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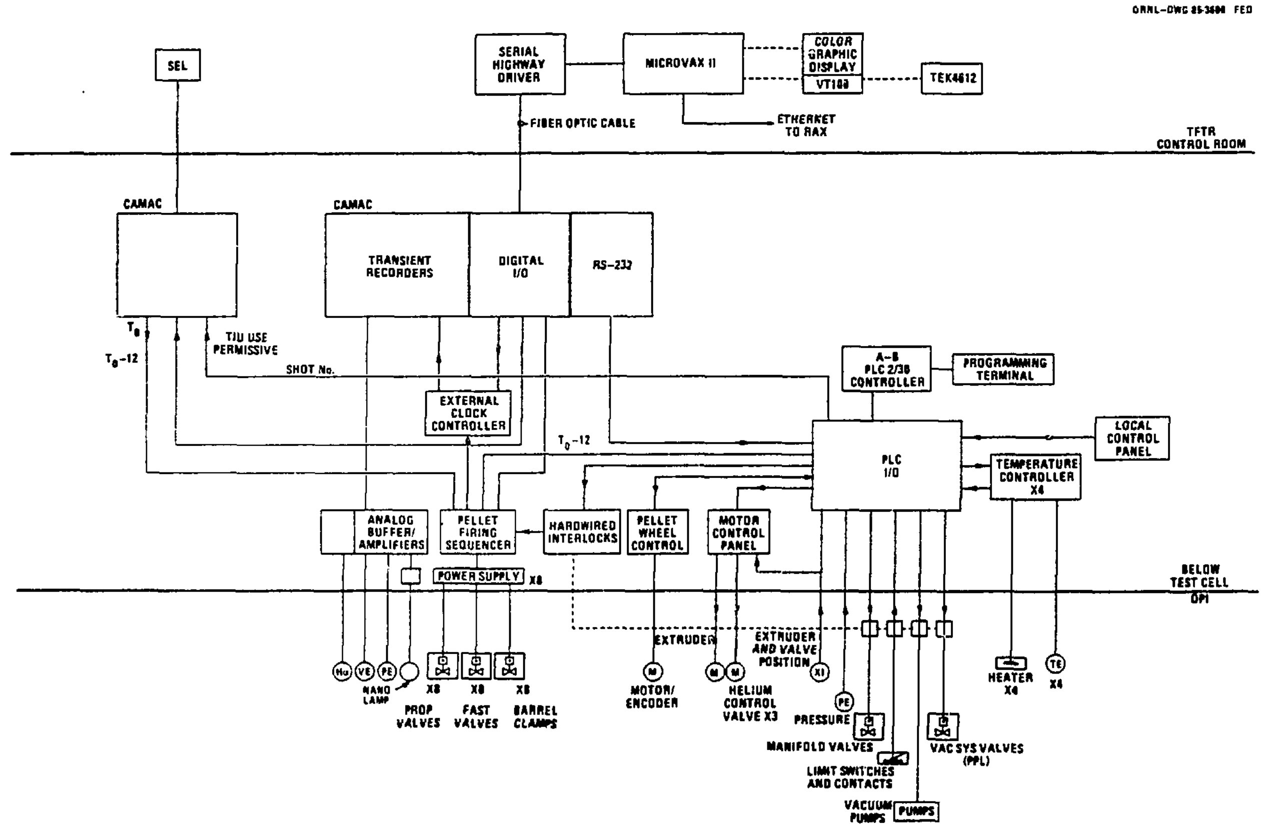

Fig. 1. DPI control system at TFTR.

intelligent panel system has a module with 32 lighted pushbuttons to operate valves in the gas manifold and vacuum systems and a keypad module used to change and display setpoints of control valves and the extruder. The intelligent panel is locked out by software in the PLC when the system is operating remotely from the VAX.

4. Remote Controls

The remote control portion of the pellet injector control system consists of the VAX minicomputer with its associated PLC communication, operator interface, data acquisition, and pellet firing sequencer software. The RPI system uses a VAX 11/730; however, the DPI and future injectors will use a MicroVAX II. A DECwriter console and two operator terminals are the user devices supplied with the RPI system.

4.1. VAX-PLC Communications

Communications with the PLC are carried out over an RS-232 link between an Allen-Bradley 1771-DA ASCII module and a Kinetic Systems 3340-D1B CAMAC module. This hardware combination provides a 9600-baud link with hardware buffering at each end and DMA transfers throughout. Traffic on the link uses less than half the available bandwidth.

COMM, the VAX task which handles the link, also dissects the strings received from the PLC and constructs the strings to be sent to the PLC as command requests. In the inbound case, status data received from the PLC are converted to Boolean, integer, or real form and stored in a shared global common memory area (INJSTATUS common) in the VAX. These data are available to all the other VAX tasks, such as the operator display and trend-saving programs.

In the outbound case, command requests entered via the operator interface task are stored in another global common memory area (CONTROL common) that the COMM task shares. These requests may be of a Boolean nature or may involve sending setpoints to the PLC. In either case, the COMM task structures an ASCII string containing the relevant data and sends it to the PLC. The string contains two copies of the data, so that upon receipt the PLC can check validity by an exclusive-or operation on the two copies. If the PLC detects a difference in the two copies, it ignores the request. This method of communication has proved to be extremely reliable. As part of the system testing, over one million bytes of data were sent in each direction with no errors encountered.

4.2. Operator Interface

The REMOTE operator interface consists of three display devices and their associated software: (1) a color mimic-panel display, with an associated trackball, driven by a Kinetics Systems 3242 display driver, (2) a menu-display terminal, and (3) a graphics terminal for display of waveform data. The operator uses the color display to view the status of the pellet injector systems and requests actions through the trackball and keyboard of the menu-display terminal.

4.2.1. Mimic-Panel System: The mimic-panel display system displays a choice of six mimic panels, each representing a subsystem of the pellet injector process. The six subsystems are the cryogenic system, the fueling gas system, the propellant gas system, the vacuum system, and two general displays of the extruder system. Each panel contains a five-line common header section containing mimic panel and menu selections, operational modes system status, and errors.

The mimic display task controls and updates these displays by reading information from the global common memory area (INJSTATUS common), converting this information to a display format, and sending the display to the Kinetics System display driver. The module then displays the updated panel on the color monitor. Operator control is provided by the trackball device. This device provides the operator with the capability of selecting a mimic panel for display and also enables the operator to toggle valves and select setpoint values to be updated.

4.2.2. Menu System: The mimic-panel system has no convenient mechanism for the entry of setpoint data, since it has no keyboard. In addition, user requirements included a display of global status information for which there was no room available on the color display. The color display size constraints required that the global status display and the menu processing system use the same VT100 terminal.

There are seven forms displayed in this system. One form is used to select other forms for viewing, and a second one displays error status related to VAX processing and communications-related events. The remaining forms are used to set up transient digitizers, control the external digitizer clocks, and prompt for setpoints for the firing sequencer, valves, and extruder controls. The software used to present the forms was written at ORNL for use on earlier fusion experiments, but systems currently under development will use Digital's Forms Management System (FMS) software.

The entry of data into a menu can be triggered in two ways. The operator may select a menu item from the VT100 by entry of a character or two specifying that item, in which case the cursor will move to that location; the operator then enters the data. Or, the operator may move the trackball cursor to a position on the mimic panel which is associated with a setpoint (such as a valve or an extruder element) and trigger the menu system by typing a carriage return (later systems have implemented a hardware pushbutton for such triggering). If the appropriate menu is not currently displayed, the system will determine the correct menu and change to it, leaving the cursor at the field to be filled.

4.3. Shot Control

The menu system allows the injector operator to select the timing parameters necessary for pellet injection into the tokamak. The parameters that must be entered include the number of pellets to be fired and the time of the pellet firings relative to the start of the discharge. These timing parameters are loaded through CAMAC modules into the pellet firing sequencer provided by the tokamak timing system, which then counts down from the tokamak timing pulses and triggers the solenoid valve power supplies that fire the pellet. The outputs from the pellet sequencer also trigger the transient recorders that are used to collect the transient pellet diagnostic data.

5. Data Acquisition

The CAMAC interface to the VAX makes it possible to use CAMAC transient recorders for data acquisition of pellet diagnostics. The pellet diagnostics from the injector include gun barrel pressure signals, speed diode signals, and hydrogen light emitted from the pellet/plasma interaction region. These signals are digitized by the transient recorders and acquired and archived by the VAX for later display and analysis. Data that are returned from the PLC during normal operation of the injector and stored in INJSTATUS common on the VAX may be archived periodically for use in analyzing the injector performance.

6. Acknowledgments

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