

*A PC-PCL-Based Control System
for the High-Voltage Pulsed-Power Operation
of the Intense Diagnostic Neutral Beam
(IDNB) Experiment*

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MASTER

**A PC-PLC-BASED CONTROL SYSTEM
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ABSTRACT

A stand-alone, semiautomated control system for the high-voltage pulsed-power energy sources on the Intense Diagnostic Neutral Beam Experiment at Los Alamos National Laboratory using personal computer (PC) and programmable logic controller (PLC) technology has been developed and implemented. The control system, consisting of a PC with the graphic operator interface, the network connecting the PC to the PLC, the PLC, the PLC I/O modules, fiber-optic interfaces and software, is described.

I. Introduction:

The Intense Diagnostic Neutral Beam (IDNB) Experiment at Los Alamos National Laboratory is a prototype for a neutral beam spectroscopy diagnostic for the next-generation, burning tokamak plasmas.¹ An intense ion source, consisting of a 50-kA, 100-kV, 1- μ s ion beam, is created using magnetic-insulated ion-diode technology. The main energy sources for the diode are plus and minus charged, rail-gap switched, 50-kV capacitor banks. Electron currents in the diode are minimized by a magnetic-insulation field provided by pulsed electromagnets located in vacuum. Energy sources for the magnets are ignitron-switched capacitors. A

personal computer (PC), programmable logic controller (PLC) based, semiautomatic control system has been developed and is in operation in this facility. As illustrated in Figure 1, the system consists of a PC with a mouse-driven graphic operator interface, a fast communications network connecting the PC to the PLC, a PLC with a down-loaded ladder logic program, PLC I/O modules, a fiber-optic interface connecting the PLC I/O modules with the field devices, and the facility's field devices. The adaptation of industrial process control technology to the experimental research laboratory facilitates the implementation of a flexible control system, which may be readily modified and expanded to match the size and complexity of the experiment.

II. Operator Interface:

The operator monitors system status, sets machine parameters and initiates shot sequencing via graphic interface software on the PC. The system organization is shown in Figure 2. The PC is in constant communication with the PLC via the fast network described below. The PLC, in turn, controls and receives information from an array of I/O devices. The I/O devices are connected either by cable or fiber-optic links to the field devices. The programmed PLC runs in a constant scanning mode, checking the safety system and PLC status. Once the operator initiates the sequence, the program in the PLC automatically sequences through the required steps for a shot. The PLC continues to monitor the safety system and various abort conditions throughout the shot sequence. The operator can abort the sequence at any time; however, all other functions during the sequence are automatic. At the completion of the shot the PLC steps through a programmed shutdown procedure.

The operator interface device is a Northgate (386 33MHz) industrial PC with a NEC MultiSync 5D monitor. The controls are mouse driven. The graphic, interactive operator interface is the FactoryLink software package available from the U.S. Data Corporation. Multiple, sequencing windows display the safety interlock system, shot-initiation operator-input functions (including a control code or password that must be entered before every shot sequence), shot parameter setup (including capacitor banks, trip voltage setting, and bank delay times), and real time bank charging voltages display. In the event the shot is aborted, an abort summary is displayed. A run manager screen pictured in Figure 3 displays the communications status with the PLC and the state of the various FactoryLink tasks. The FactoryLink software is a real-time, application and technology enabler software package running on the OS/2 platform. This software includes various tasking capabilities including a run time manager, animated color graphics, timers, math and logic procedures, a report generator, programmable counters and an external device driver to interface with the communications network. To date, the software has been pre-released versions with inherent bugs and difficulties.

A drawing, shown in Figure 4, of the 3-floor experimental layout is displayed on the primary window or panel. This drawing has all the interlock devices displayed with animation to indicate the status of each device. An animated symbol clearly indicates if the interlock system is complete ("swept") or not. If the sweep is open, the operator can from the drawing determine which devices need to be reset. The panel also has indicators as to the status of the vacuum system, the SF6 and SF6-Ar insulating gasses, air pressure to operate air solenoids and the abort state. The primary window also has buttons to set the shot type, automatic or calibration. After starting the automatic mode, the PLC carries the shot sequence through to completion. In calibration mode, the PLC charges the banks to the preset voltage and then waits for an operator input to trigger or abort the system. If the operator waits beyond a preset time, the system will automatically abort the shot, discharge the capacitor banks, and return the system to the normal, safe state. This mode is used for troubleshooting and calibrating the voltage monitors. Another button allows the operator to run without the vacuum system. Other buttons on this panel allow initiation of the shot sequence. The control code is a password that must be "silently" entered on this panel.

Once the control code is entered and the shot initialization buttons have been "pressed," the panel changes to the shot parameter panel represented in Figure 5. From this panel the operator can select which banks are to be charged on this shot and their respective charge voltages (the trip level). The operator can then select another panel shown in Figure 6, and set a charging time delay so that all banks will reach their trip voltages simultaneously. A time panel, pictured in Figure 7, is available to enter approximate bank charge times so that upper and lower running limits can ensure that the bank is charging correctly; when outside these limits, the PLC aborts the shot. If the capacitor banks charge within a very few seconds, it is generally too fast for this feature to be useful. The system cannot respond on time scales less than about 1 millisecond reliably.

When the operator has completed entering the shot parameters, the button to start the automatic sequence is "pressed." The software checks to see that the entered trip levels are below preset values and that certain conditions and combinations of devices are correct. If it finds an inconsistency, the operator receives a message and the setting can then be corrected. Once a compatible set of parameters has been entered, the button can be pressed again. If the selections are acceptable, the automatic sequence will begin.

As the automatic sequence begins, the display panel switches to that shown in Figure 8, with a set of bar graphs that display the real-time charge voltages on the various banks. The trip level and the actual real-time voltage are also displayed numerically below each graph. If the running limits are implemented, these are

displayed on narrow bar graphs one on each side of the main graph. If an abort occurs, a flashing symbol appears and the cause of the abort is displayed. When the shot is fired, the graphs show the rapid return to zero of the voltages on the banks.

At this point the operator may return to the primary panel to begin the sequence again.

III. Communication:

Two-way communication between the operator interface software and the Modicon PLC is through a Modicon SA85 board (Modbus Plus adapter for the IBM-AT bus) and the associated Modsoft SA85 Device Driver software. The SA85 board plugs into the PC and connects to the Modicon 984-685 PLC by means of a shielded twisted pair cable. Modbus Plus is a 1 M baud, peer to peer token passing protocol, local area network. This network is used for the operator interface to communicate information to and from the PLC. It is also the means by which the ladder logic, programmed on the PC, is downloaded to the PLC.

IV. Programmable Logic Controller:

The operator supplies and receives only minimal information to and from the PLC; the actual control program resides in the Modicon model 984-685 PLC. The control program performs safety monitoring, sequencing, charge voltage monitoring, and abort instructions. It is programmed in ladder logic using the Modicon Modsoft Programming Software on the PC. Modsoft is an integrated development / troubleshooting ladder logic programming package running on a DOS platform. The completed ladder logic program is downloaded from the PC to the PLC on the Modbus Plus network. After the program is loaded into the PLC, the PLC is set into the run mode and the program remains constantly active in its monitoring mode. The Modicon PLC, I/O modules, Modsoft and the Modbus Plus network are products of Modicon Inc., an AEG company.

During system checkout and to implement modifications to the control system ladder logic, a second AT type PC (286 8mhz) is used for the Modsoft program. An on-line debugger is available to watch the power flow in the ladder logic networks and to monitor register values. This is a valuable tool in implementing the control system for the facility. Once the system is functional, the second PC is unnecessary and the ladder logic remains in the background, invisible to the operator.

Modicon I/O modules are housed in Modicon racks with the PLC. There are 3 "drops" in the system. A "drop" is one Modicon location. It may contain multiple racks and I/O modules. The IDNB control system has 3 drops. The primary drop which houses the PLC is located in the shielded control room for the facility (safety

system controls are housed here). There are two remote drops, one located in the power supply room (primarily controlling the electrical system) and the other near the front end of the experiment (for future automatic vacuum system control). The drops are connected through a Modicon S908 remote I/O processor and an EoTech fiber-optic link. The Modicon I/O modules implemented in the system are the B837-016, a 24V ac/dc, 16-channel digital input module; the B814-108, an 8-channel, relay digital output module; and the B875-101, a "high-speed" (2.4 ms data update period), 8-channel, analog-input module, a 12-bit module with a maximum input of +/- 10 volts.

V. Interconnections:

All control signals coming from or going to the control room are fiber-optically coupled to reduce electrical noise in the control-room and to isolate the control system from high-voltage transients. The control room Modicon I/O modules are connected to 12 channel, fiber-optic transmitter or receiver modules. The remote drop I/O modules are connected to the field devices through buffer modules schematically represented in Figure 9.

Almost all of the safety system components are connected to the control-room Modicon drop through fiber optics. Fiber-optically coupling these signals eliminates ground loops and minimizes electrical noise pickup. The interlock chain, scram switches and the sweep-reset switches are fiber-optic switches available from Weed Fiber-Optics, Inc. A light signal is sent from the control room on one half of a fiber-optic zip-cord cable manufactured by Ensign-Bickford Optics Company and terminated with their SMA connectors. The light is returned through the fiber-optic switch on the other half of the zip-cord cable. When the switch is activated, a shutter prevents light from passing through the switch. The switches and Modicon logic are failsafed, i.e., designed to operate such that light must pass through and be received in the control room to complete a safety circuit. The interlock chain switches when not depressed do not pass light, i.e., the door must be closed to depress the switch. The scram switches when pressed do not pass light. They must be in the pulled out position to pass light, the necessary condition to operate the facility. The sweep-reset switches are momentary switches that pass light only while the switch is depressed. The signal is latched in the Modicon PLC until any signal on that reset switch's circuit goes off and then the sweep is broken. The sweep must be completed to operate the facility; the shot sequence cannot start without the presence of this condition. Furthermore, if the sweep is broken during a shot sequence, all control power for the high voltage systems is instantly turned off and an abort shutdown sequence is activated.

The warning lights, Klaxon, charge-complete bell and all-clear bells are part of the safety system. Light emitting diodes (LEDs) are activated by the PLC at the appropriate times in the sequence to turn these devices on. An optically-controlled solid-state relay switches the 110V ac power to activate these devices, with the exception of 3 signals in the power supply room that are hard-wired, very short runs to the electrical system Modicon drop.

The electrical system is primarily hard-wired from the buffer modules to the field devices, with the exception of signals that must go to the vicinity of the front end of the experiment. These signals are fiber-optically coupled to eliminate ground loops and minimize electrical noise.

At present, the vacuum system controls are manually controlled; however, automating this system with the PLC is quite straightforward.

A PC and CAMAC-based data-acquisition system has been implemented to take, store and display the experimental data. This system utilizes National Instruments Lab Windows software package interfaced with GPIB communications to the LeCroy 8901A GPIB CAMAC crate controllers. The data-acquisition PC sends and receives signals using the National Instruments multifunction I/O board for the IBM PC/AT. During the automatic sequencing, signals are sent via the PLC I/O modules to and from the data-acquisition PC to actuate its initialization process. The data acquisition system then responds when it has completed its initialization. The PLC waits for this signal to proceed. During the shutdown procedure, the PLC again sends a signal to the data-acquisition system to begin the CAMAC read sequence. The operator interface software sends the selected shot parameters to the data-acquisition system for storage with the shot data.

ACKNOWLEDGMENTS:

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REFERENCE:

1. D. J. Rej, I. Hennins, R. J. Fonck, Y. J. Kim, Rev. Sci. Instr. 63, 4934 (1992), "Intense Diagnostic Neutral Beam Development for ITER."

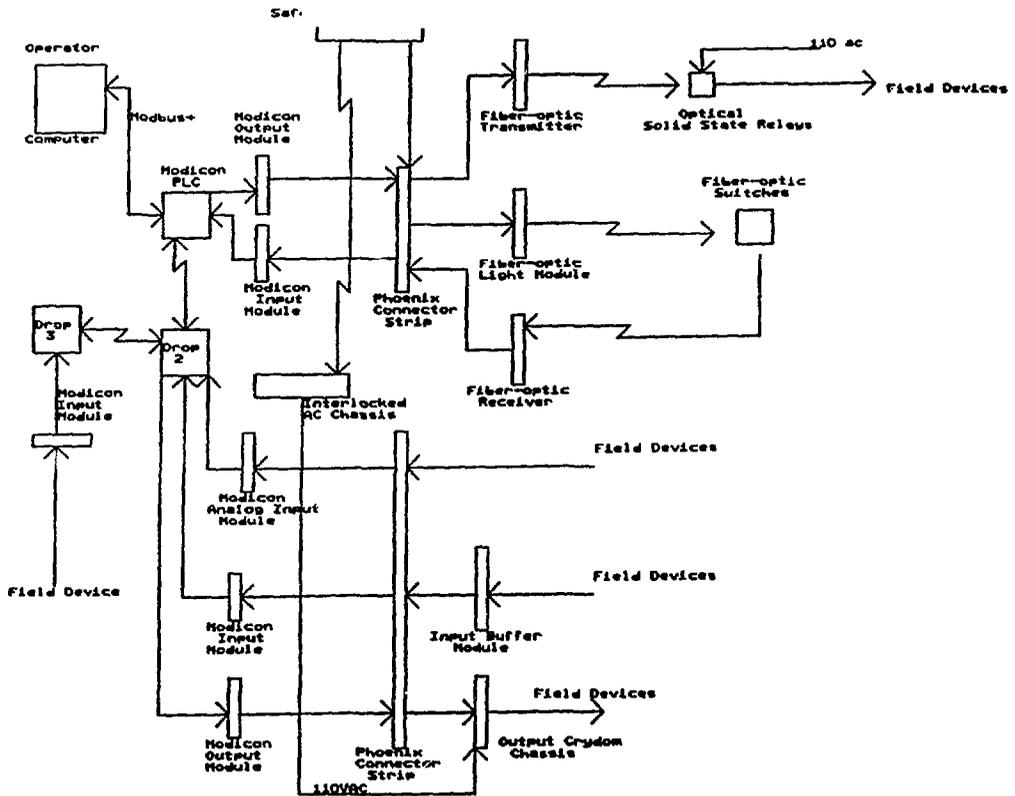
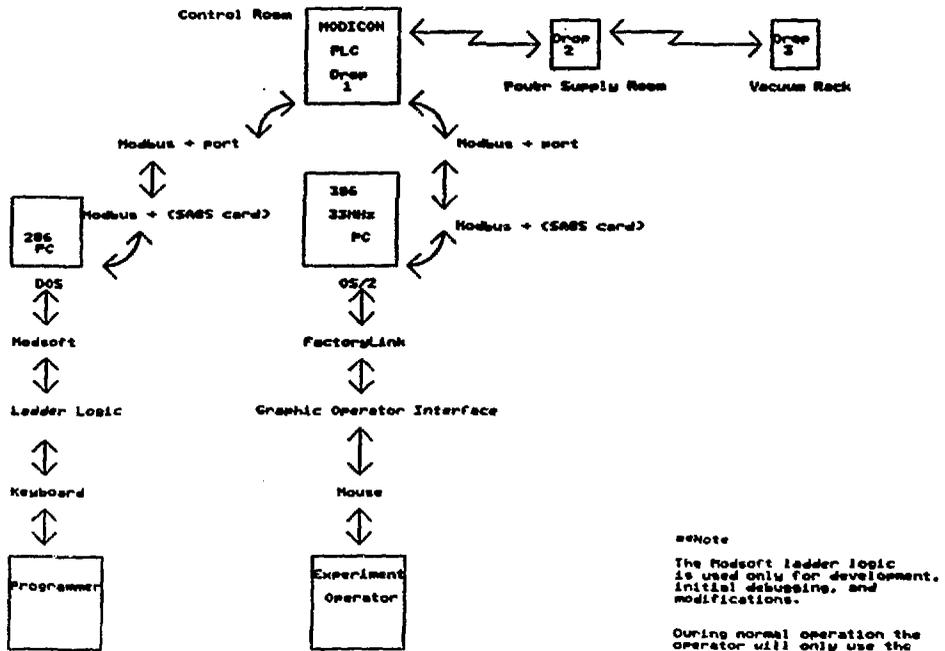


Fig. 1. Block diagram of the IDNB control system.



IDNB Control System

Fig. 2. Block diagram of the computer PLC section of the IDNB control system.

FactoryLink Run-Time Manager		
TASK	STATUS	MESSAGE
RUNMGR	Active	running
GRAPH	Active	running
TIMER	Active	running
ALOG	Inactive	no control function defined
IMI	Active	running
COUNTER	Active	running
BPT	Active	running
BIN_HIST	Active	running
SPOOL	Active	running
LD	Active	not controlled

F2 ROOM

F3 QUIT

Fig. 3. IDNB control system Run Manager screen.

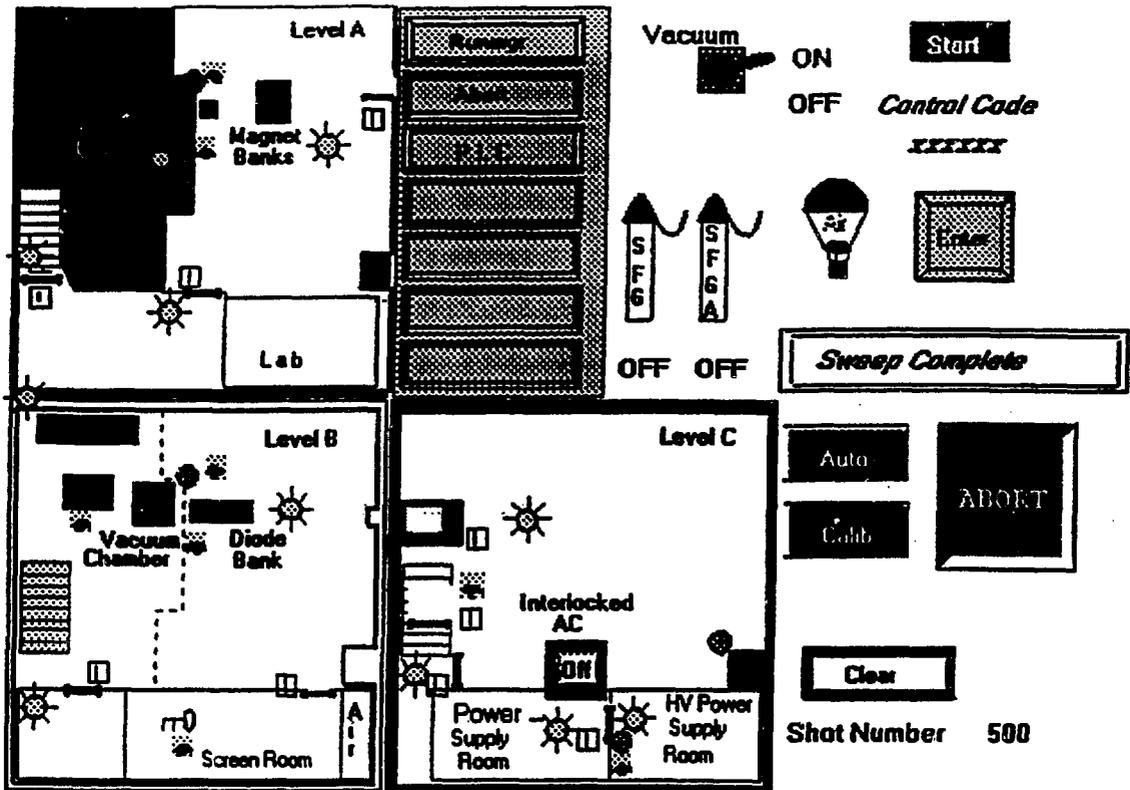


Fig. 4. Panel showing the experimental layout with the interlock system status, abort status and the shot sequence initialization buttons.

PARAMSET.G

<i>Shot Setup Parameters</i>	<i>Include</i>	<i>Trip</i>	
Positive Main Bank	<input type="checkbox"/> On	30 KV	START SHOT SEQUENCE
Negative Main Bank	<input type="checkbox"/> On	30 KV	
Main Bank Trigger	<input type="checkbox"/> On		
Inner Coil Bank #1	<input type="checkbox"/> On	700	<i>Include</i> <i>Trip</i>
Outer Coil Bank #1	<input type="checkbox"/> On	350	Inner Coil Bank #2 <input type="checkbox"/> OFF
Fest Coil Bank	<input type="checkbox"/> On	2000	Outer Coil Bank #2 <input type="checkbox"/> OFF
Puff Valve Bank #1	<input type="checkbox"/> OFF		Error Message
Puff Valve Bank #2	<input type="checkbox"/> OFF		<input type="button" value="Error-Retre"/> <input type="button" value="Cancel"/>
Data/No Data	<input type="checkbox"/> DATA		<input type="button" value="SELECT"/> <input type="button" value="RUNNGR"/> <input type="button" value="DELAY"/> <input type="button" value="TIMESET"/>

Fig. 5. Shot parameter setup panel.

*Enter approximate time
in SECONDS
to DELAY the start of fast banks*

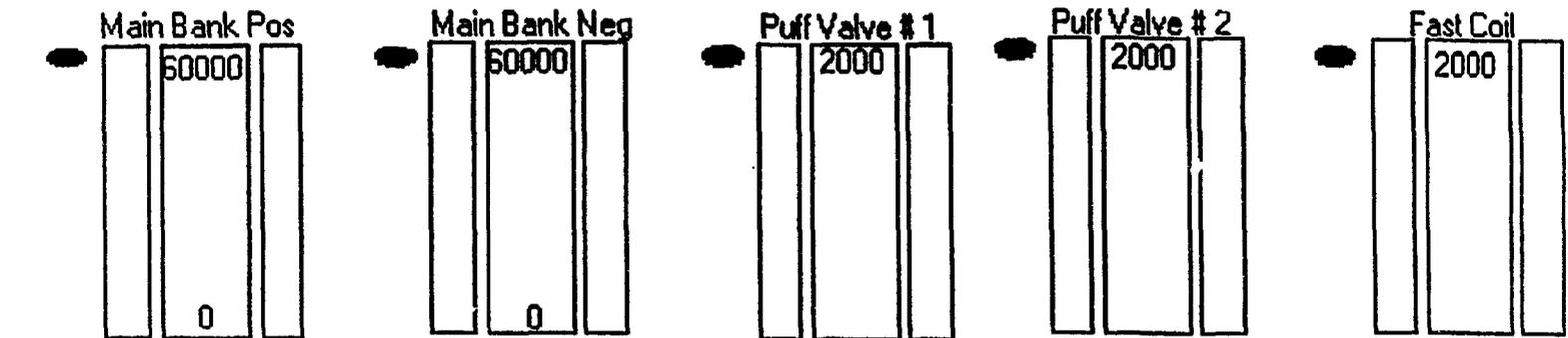
<i>Bank Delay Time</i>		<i>Trip</i>
Positive Main Bank	2	30
Negative Main Bank	2	30
Main Bank Trigger		
Slow Coil #1 Bank		700
Slow Coil #2 Bank		350
Fast Coil Bank	3	2000
Puff Valve #1 Bank		
Puff Valve #2 Bank		
Slow Coil #3 Bank		
Slow Coil #4 Bank		

 Delay Set

Fig. 6. Panel used to set the start delay times for the faster banks. Times are set so all of the banks will reach charge complete at approximately the same time.

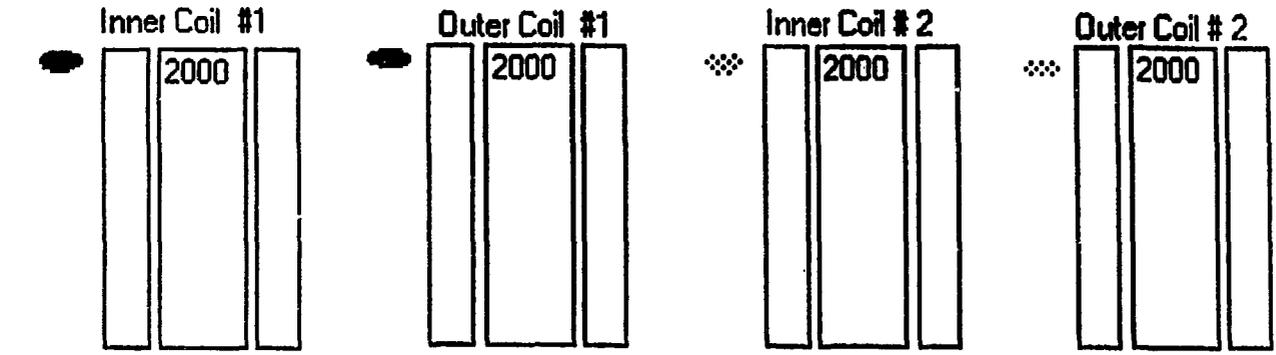
<i>Bank Charge Time</i>		<i>Enter approximate time in SECONDS for each bank to charge</i>	
		<i>Trip</i>	
Positive Main Bank	2	30	
Negative Main Bank	2	30	
Main Bank Trigger			
Slow Coil #1 Bank		700	
Slow Coil #2 Bank		350	
Fast Coil Bank	3	2000	
Puff Valve #1 Bank			
Puff Valve #2 Bank			
Slow Coil #3 Bank			
Slow Coil #4 Bank			 TIME SET

Fig. 7. Panel to enter the approximate bank charge times for running upper and lower limits.



Volts
Trip
Time

Abort Status



Volts
Trip
Time

13

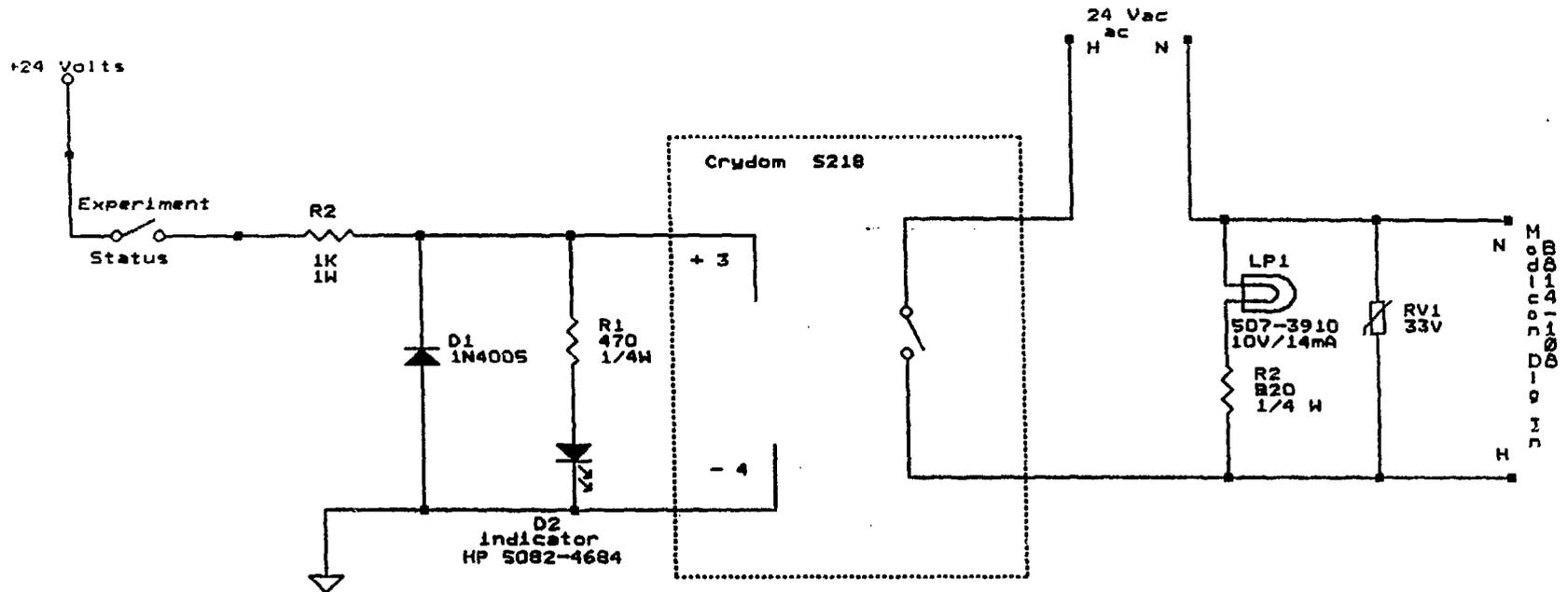
Select

Shot Number 500

Manual Trigger

ABORT

Fig. 8. Bar graph real-time display of the charging bank voltages.



• NOTES

Build in 8.75 in. double wide NIM module

8 Channels per module

indicator led on front panel

Amp connector as per standard NIM back panel
for inputs from Modicom

Amp connector on top of back panel
for switched 24V ac switched outputs

Lamp on front panel

Fig. 9. Schematic diagram of the buffer modules used to isolate the PLC from the experiment.