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A DESCRIPTION OF THE PLASMA POTENTIAL CONTROL (PPC) SYSTEM ON THE TANDEM MIRROR EXPERIMENT-UPGRADE (TMX-U)

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Abstract

A set of 18 separately controlled plates have been added to each end of the Tandem Mirror Experiment Upgrade (TMX-U) vessel to allow measurement of end-wall currents and to provide a means of plasma potential control (PPC). These plates are shaped to form elliptical rings separated into quadrants. Each plate can be individually grounded, float at plasma potentials, or be actively biased to control the plasma. Voltage and current monitoring are provided for each of the plates, and the control and monitoring functions are controlled by the PPC system computer. The details of the field line mapping and the plate shapes are discussed, and the control architecture and performance are presented.

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Introduction

Results from the Tandem Mirror Experiment-Upgrade (TMX-U) demonstrate that radial transport in the plasma volume can be affected by the electrical and mechanical conditions at the end walls of the vessel [1]. Transport reduction is necessary for longer tandem-mirror confinement times. Experiments on the TMX-U at Lawrence Livermore National Laboratory have produced results that substantiate modifying end-wall boundary conditions using floating, ring-shaped plates. This gave rise to the Plasma Potential Control (PPC) System which provided a means to further measure this phenomena. These measurements (in which the end-wall plates, mapping to the plasma core, are switched from a floating to a grounded condition during plugging operation) demonstrate that this floating increases the build-up rate of the central cell plasma, steepens the core density profile, and affect the plasma throughout the entire cross section.

To obtain these experimental results, the plates need to have a mechanism to change their electrical status during a typical 100 millisecond shot of TMX-U. Three electrical states with respect to the TMX-U vessel, grounded, floating and some bias potential, further complicate the installation of the equipment. To obtain data on the effects the plates have on confinement, each plate needs to have the ability to change electrical states (possibly several times) during the course of the shot. This mandated the use of a computer system and control architecture to provide the required precision timing. This paper discusses the PPC system and the performance levels achieved.

Plate Requirements

For the initial installation of PPC in the TMX-U, the plates cover about 80 percent of the total area in each end wall. The end walls are rotated 90° from each other so the elliptical plates are also rotated, which conforms to the Tandem Magnetic Mirror configuration of TMX-U (see Fig. 1).

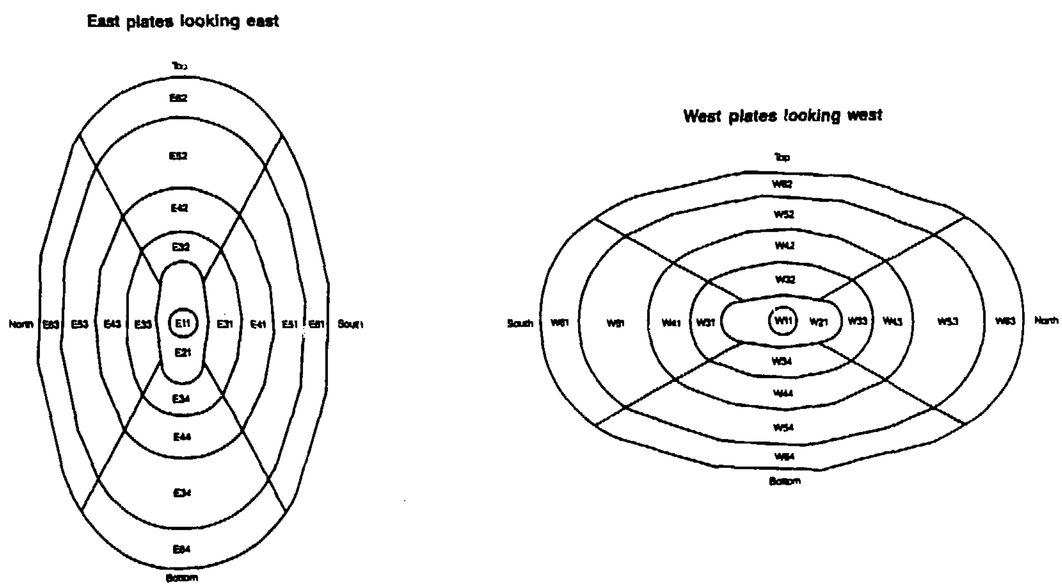

Figure 1. Plate Configuration

These plates are separated into six rings; the outer four rings are divided into four-quadrant plates; the two inner-plates are solid. All the plates are electrically isolated from each other and from machine ground. The plates are mapped end-to-end along the magnetic field lines of the plasma region so that each plate has its complement on the opposite end wall. This brings a count of 18 plates per end or 36 plates in all.

Each plate needs to have the capability of being individually controlled in three electrical states, floated, grounded, or biased. A floated plate is isolated from ground thereby providing a neutral end-wall boundary. A grounded plate is at the same ground potential as the real-end wall of the vessel. Providing a potential on each plate, either negative or positive, provides the capability of biasing the plates to enhance plugging and increasing confinement times. These three electrical conditions increased the control complexity by three times the 36 plates or 108 possible electrical combinations.

Plate Switching

Each plate requires a three-position switch to control the three electrical states possible. This switch needs to control up to a 5-kilovolt bias potential at up to five amps and a virtually unknown potential and power of the plasma. This required a rugged device that would be relatively forgiving of possible excesses. A configuration of two high-voltage relays was selected to handle the three control states (see Fig. 2).

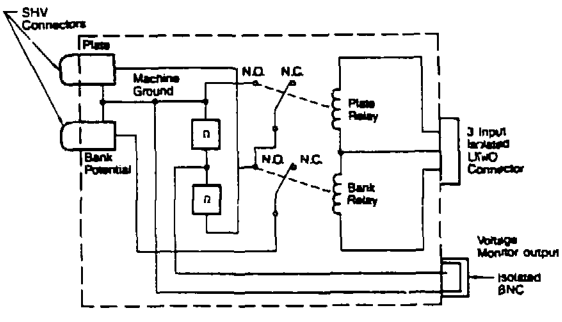

Figure 2. Relay Switch box

The idle or normally open positions of the relays provide for the floating condition. One relay provides the switch to a potential source and the other relay provides the switch to ground. The relays have proven to be a reliable switch yet have the rating protection required to forgive the over build up of plasma potentials that will happen on an experiment such as TMX-U.

Relay Control and Timing

Relays have basic problems with timing that are not normally encountered with solid-state devices, especially relays capable of handling 5 kv at 5 amps. The inductive and resistive nature of the coil require some time to build a field to operate the switch and then more time for the field to die so the switch will go back to the normal position. Since physics shots are only 100 milliseconds on TMX-U and several switch transactions may be required per shot, a shot window accuracy of 50 microseconds was necessary. The relays were found to be very repeatable in their switching times as long as the coil voltage supply is highly regulated to maintain a constant supply voltage. However, each relay had a different on time as well as off time. Each relay was cycle tested 100 times with the "ON" and "OFF" times recorded. The mean average was then taken to determine the reliable switching time of each relay. These times were then used by the PPC computer to adjust the "ON" and "OFF" times of each relay per physics timing requirements. In this manner, the relays have proven very reliable with a repeatable accuracy of under 10 μsec.

To handle this needed timing adjustment, a computer system was introduced centered around a Hewlett-Packard Series 200 machine called, "The 9816 Personal Computer." The computer makes the number crunching required to adjust the "ON" and "OFF" time of each relay manageable (see Fig. 3). The operator enters the requested "ON" and "OFF" time at each possible plate condition. The computer will then store these raw timing arrays on a floppy disc, to be recalled quickly at any time. Before the timing information is sent to each control, it is adjusted with its unique set of required switching times. This system ensures the 50 μsec accuracy required of each relay.

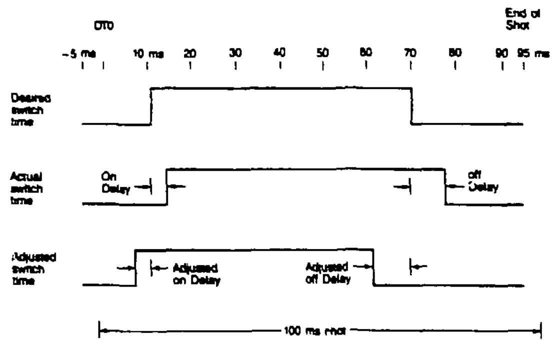

Figure 3. Relay Switching Times

Operating Environment

The nature of the TMX-U provides for a very hostile operating environment, especially to a system that is trying to establish the accuracy required by the physics application. Very high-magnetic fields are generated in close proximity to the vessel where the relays are positioned. There are also high levels of electro-magnetic interference to cope with from the great levels of energy pulsed into the machine during each 100 millisecond shot.

Handling the operation of the relays in the large magnetic field proved relatively simple. The relay boxes were placed perpendicular to the magnetic lines of flux generated by the machine. In addition, the relay boxes were mounted on a 1/4" soft iron plate and another soft-iron plate covers the entire assembly. This provides an affective magnetic shield to allow normal operation of the relays.

Handing the electronic interference was much more difficult. Since personnel are not allowed in the immediate vessel area during a TMX-U shot due to safety considerations, all control is done remotely from the machine with distances to 100 meters. To provide for better diagnostic measurements and accounting for wire losses, equipment racks were installed at each end of the vessel no more than 5 meters away from the flange where the cables exit the vessel. Each rack houses the switches and monitoring equipment for the 18 PPC plates on that end of the machine. To handle the communication between these two racks and the operator, a CAMAC (Computer Automated Measurement And Control, IEEE Std 583-1975) system was employed using a serial highway interface system conforming to IEEE Std 595-1976 (see Fig. 4). Since the electro-magnetic interference is such a concern, no switching data is transmitted over the long distance between the control room and the pit racks during a TMX-U shot. The switching times are stored in LeCroy 8201 memory modules located in each CAMAC crate. This switching data is then clocked through to a memory buffer module installed immediately next to each memory module during each 100 msec shot. The memory buffer module contains data bus buffers, data latches, and the Field Effect Translstors (FETS) that ultimately control each relay. Each memory module and memory buffer combination handles 6 plates or 12 relays, making three sets necessary in each CAMAC crate to control the 18 plates via the 36 relays at each end of the machine. The memory module has 16K bits of memory available and can be configured in either 8-bit or 16 bit words. PPC uses a 16-bit word of which 12 bits are actually used to switch the 12 relays. This allows 1K of memory per relay and a total use of 12K for the switching data. Because of the high potentials switched at each of these racks, a fiber optic serial highway was installed to provide the necessary isolation between the operator and the PPC switching racks. This scheme of control has proven very reliable with essentially no collision of the switching relays, which would prove catastrophic, even in this very hostile operating environment.

Shot Timing

Timing in the PPC system and therefore operation of the relays has to be in synchronization with the whole TMX-U Project during a shot. To accommodate this precision, the "GO" signal to start the timing sequence and consequently clock through the timing data stored in each memory module, is generated at the TMX-U master timing computer. This go signal is then sent via a fiber optic link to each CAMAC crate at the vessel (see Fig. 5). The "GO" signal is processed by a Honeywell LED transmitter and receiver set that operates at a very stable 2.5 MHZ during idle or "0" mode and 5 MHZ at the "GO" signal or "1" mode. Since this frequency is very reliable, the 5 MHZ is used to generate the timing to clock through the timing data stored in each memory module to the memory buffer module. The 5 MHZ is divided to achieve a 10 kHZ clock by one of the memory buffer modules at each rack. This clock rate is then sent to the other two memory buffer modules and to their own respective memory modules thereby clocking and latching the data out of the memory module.

A 10 kHZ clock rate allows 10 data bits per millisecond and a 100 msec resolution overall. During the 100 millisecond shot, each 12-bit word (one bit for each relay) is clocked from the memory module to the memory buffer where it is buffered and latched to either turn the relay driving FET "on" if a "1" is present or "off" if a "0" is present. This method of control provides the immunity to noise which would otherwise cause false triggering and erroneous data to be collected.

Diagnostic Data

Besides the ability to aid confinement in the TMX-U vessel, the PPC plates provide an important diagnostic tool to help understand the plasma action. When the plates are in the floating mode, they are tied to a resistive divider network which measures the electron potential at each plate. In the grounded mode, the PPC system is capable of measuring electron current on each plate through a Hall Effect transformer in series with the lead from the plate. When the plates are externally biased, the voltage and current data can also be collected in the same manner. This data is then sent to the main data acquisition computer (an HP 1000 System) for ultimate storage and interpretation of the entire PPC system. The PPC computer has also been programmed to diagnose the response of the relays and call the operator's attention to poor timing tolerances. The graphics of the computer has provided an excellent means for providing the switching pattern of the relays both before a shot and after the shot so a comparison of the desired switch time with the actual switch time can be made.

Biasing

The PPC plates have the ability of being biased by two available voltage levels. Two 7200 μfd capacitor banks are available for voltages up to 5 kV at each rack. These capacitor banks are independently controlled, remotely from the PPC operator's console in the control room. The ability to make two different potentials available to the plates gives the PPC system even more flexibility.

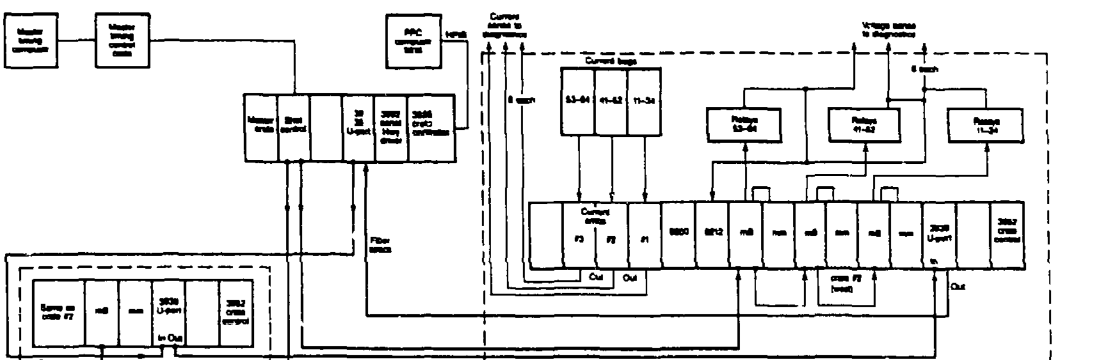

Figure 4. Control Architecture

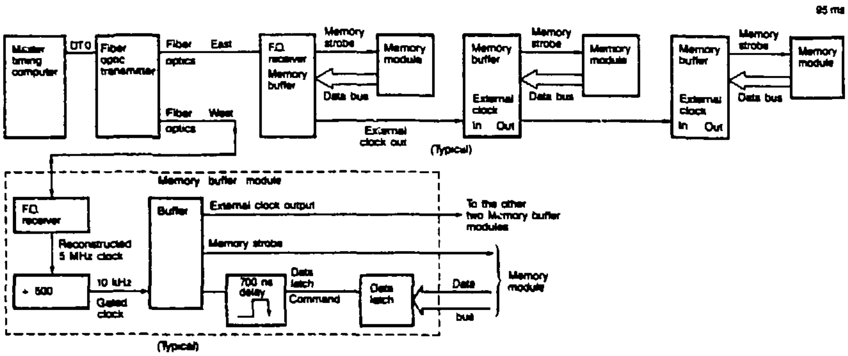

Figure 5. Shot Timing

Computer System

As mentioned earlier in this paper, the PPC system employs a Hewlett-Packard 9816 personal computer with a dual, mini-floppy disc drive and an Ink Jet printer. The main purpose for using the computer is to provide an efficient method to control and adjust the switching times of the relays. A secondary reason for using the computer is the ease of interfacing it to the CAMAC system.

The control program is menu driven and has many self-help routines that are intended to make it very user friendly. Very little instruction is needed for the operator to become proficient on the PPC system because of the 12 soft keys or menu selections available from the key board. The computer system virtually takes care of itself during normal operation, after the operator initially sends the desired timing array to the memory modules. The only required interaction by the operator after the initial operation is if the timing array is to be changed. The system detects each TMX-U shot and records the date, time, array used and any switching errors on floppy disc and provides for a hard copy printout. This provides the operator and physics personnel with a permanent record of PPC activity.

Making a new relay timing array is the primary use of the computer and requires the most user interaction. By single-key commands, the operator types in the switching times and one of the three electrical states available for each of the 36 plates. The computer then organizes a switching array complete with each relay's inherit delays and corrections and stores it on floppy disc under a name the operator can refer to for future use. Each of the stored arrays can be called back for transmission to the memory modules when required. The computer system will also provide the user with a hard copy printout of the array switching pattern for each end of the vessel.

The expandability of this Hewlett-Packard Series 200 computer and the CAMAC system has provided a means for constant improvements. Future experiments will take advantage of this growth ability.

Conclusion

Performance of the system has been tested and stressed daily since it was first installed. The ruggedness of the relays is a must because under actual operation the original parameters are routinely exceeded by more than a factor of ten. PPC is put together in a modular fashion to provide for ease of maintenance which has resulted in limited down time and no loss of operation during physic's operations of the TMX-U.

The PPC system has proven to be a huge success in its ability to affect the plasma operation and reduce spacial ion transport. The ability to provide additional end loss diagnosis has also proven invaluable. Future experiments include a more extensive set of plates and additional diagnostics to further study their effect on the plasma.

Reference

[1] E. B. Hopper, Jr., D. E. Baldwin, T. K. Fowler, R. J. Kane, and W. C. Turner, Radial transport Reduction in Tandem Mirrors Using End-Wall Boundary Conditions, Phys. Fluids, 27, 2267 (1984.)