Design of an Automation and Control System for PUPR-MC Plasma Machine [1]

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ABSTRACT

The automation of Polytechnic University of Puerto Rico Mirror-Cusp (PUPR-MC) plasma machine is part of the work performed by the Plasma Engineering Laboratory in the experiments of the NASA Solar Probe Mission Thermal Protection Risk Assessment, executed in collaboration with Johns Hopkins University's Applied Physics Laboratory. PUPR-MC was selected for these experiments due to its capacity, both in range of operation and stability. The automation process consisted in the design of the sequence of operations to safe start-up and shutdown of the plasma device. This sequence of operations were extracted from the experience of various operators, and written into a flowchart. The sequence was automated using a Programmable Logic Controller (PLC), working together with a set of electromechanical and electronic actuators. The PLC receives information from a vacuum measurement system and from a temperature measurement system to assess in which stage of operation PUPR-MC plasma machine is, generating the appropriate control signals. The operation can be switched from manual to automatic mode, allowing the operator to take control of the operation at any moment, if needed. The system has improved the speed and precision of the operations of PUPR-MC, by reducing the sources of human errors. PUPR-M is the only machine of its type in the Caribbean that has been setup for automatic operation. [1]

INTRODUCTION

Due to PUPR-MC greatest capability to produce plasma and the experience of researchers at PUPR Plasma Laboratory, Johns Hopkins University and NASA Goddard Space Center, offer the institution the opportunity to model the first test of the Solar Probe Mission [9]. The main advantage of PUPR-MC plasma machine (Figure 1) is that it can produce plasmas with electron temperatures between 0.1 eV to 30 keV, (even more in the hot electron ring region), and densities between 10^4 to 10^{11} cm^{-3}. Furthermore, the practical design of this device, including its large size, the possibility for switching gases to generate different plasmas, and the large number of ports to penetrate the device allows several experimental applications. The applications include: space plasma, solar wind plasma and ionosphere plasma conditions, ions implants, ion propulsion studies and test of new plasma diagnostics, among others. This machine has been used for a number of researches [2, 3, 4, 5, 6] thanks to its unique characteristics and versatility. This machine creates plasma via Electron Cyclotron Resonance Heating (ECRH) using a microwave

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generator and magnetic confinement. One of the advantages of PUPR-MC is that it is furnished with two Helmholtz coils able to work in two configurations: Spindle Cusp and Mirror mode. The plasma is created by ionizing the gas contained in the machine chamber and confining the ions through the magnetic field generated by the Helmholtz coils. The ionization is achieved by heating the atoms, so that the electrons on their outer orbit are free to move. At this point, electrons are moving so fast that the ions are not able to recombine with them, so the matter stays in an ionized state, called plasma. Plasma parameters, such as temperature and density, can be measured in this machine using a Single and Double Langmuir probes, and a data acquisition system developed by students from PUPR. For more detail on plasma data acquisition refer to [6] and [8].

DESCRIPTION OF THE AUTOMATION PROCESS

This work is part of a bigger effort to fully enable automatic operation of PUPR-MC. The objective pursued in this first stage was to enable the plasma machine to start up and shut down automatically with minimal human intervention, and to lock out the possibility of mistakes during those processes. The benefits expected from this automation were:

- To accelerate the procedure to perform

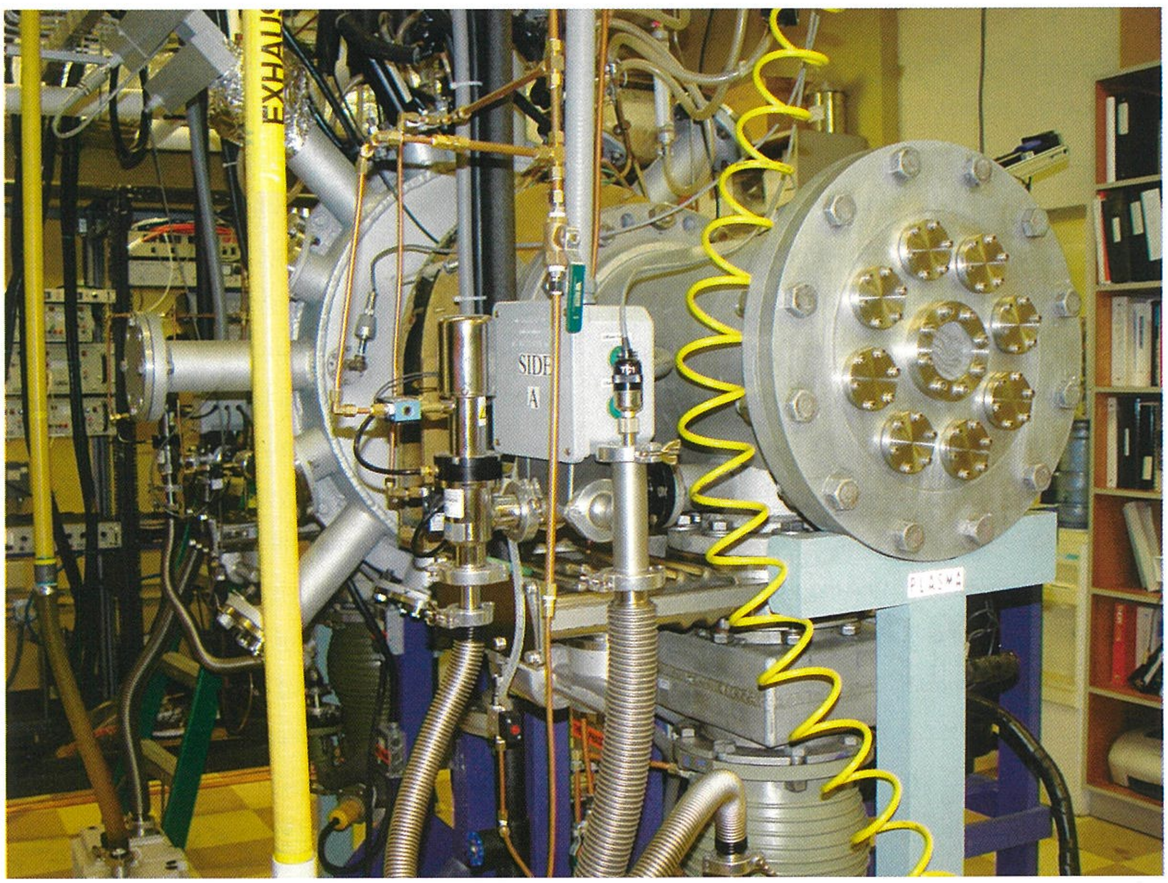

Figure 1: *PUPR Mirror and Cusp Plasma Machine*

experiments.

- To facilitate the operation of the plasma machine.
- To lay the bases for fully automatic operation in the future.
- To improve personnel and equipment safety.

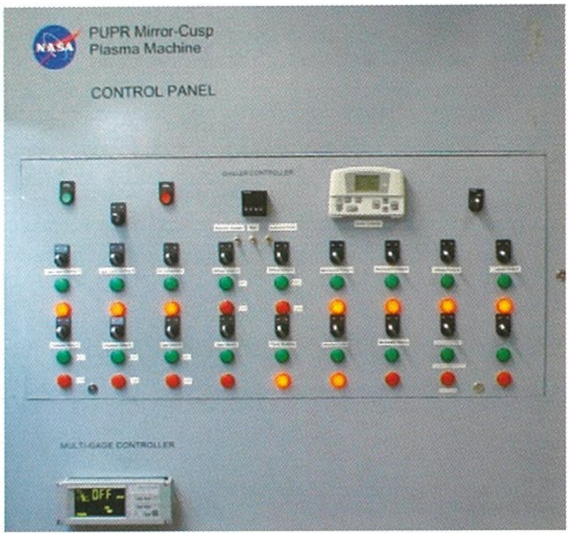

***Figure 2:** Control Panel*

Two major constraints were placed on this design, to provide for manual operation without intervention of the Programmable Logic Controller, and to provide scalability to enable the implementation of full automatic control of the plasma parameters in future works. Both of these constraints were taken into account in the design process. The first step in design was to gather information about the operation of the machine. Several operators were interviewed in order to formalize start-up and shut-down sequences, because each of them had different ways of performing these. As a result, the sequence was formalized and written in a flowchart. Three operational stages were identified, and the conditions for these stages were defined. These three stages define the state of all the equipments associated with the startup and shutdown process, and allow the designer to ensure that the proper course of action can be taken when a problem arises. To proceed with the automation design, an assessment of the existing equipment was made. All vacuum valves that controlled the vacuum pumps operation were manual, unfit for automation. The equipment used for vacuum measurements was 30 years old, not equipped with any kind of interface to provide feedback measurements to the control system. The connection and disconnection of the DC-Current Power Supplies, cooling traps, air compressor, etc., were performed manually. Hence, for the development of this system, the vacuum valve and the vacuum measuring system had to be replaced with new equipment. At this point, specifications for new equipment to be installed were prepared. Once the equipment was acquired, the installation and programming tasks took place. The new equipment included, of course, the controller itself, contact relays, pneumatic vacuum valves, and the vacuum measuring system. A control panel (Figure 2) was designed to centralize all the operations and contain the selected equipment. The control panel contains a number of electromechanical relays that work both under manual and automatic modes, keeping the underlying logic to avoid dangerous and out of order operations. Figure 3 shows a section of the schematics developed during the design.

IMPLEMENTATION

Controller

The PLC used was a SLC500-5/05, as shown in Figure 4. This controller is the most powerful inside the SLC-500 family. It has a modular design and multiple communication ports. Also it has an integrated web function, network compatibility and has wide variety of expansion cards (See reference [7]). The SLC-500 PLC was programmed using RS Logix 500 Pro 7.1. The program works using the same logic performed by the electromechanical relays. The computer communicates with the controller through Ethernet interface [1] to download the program.

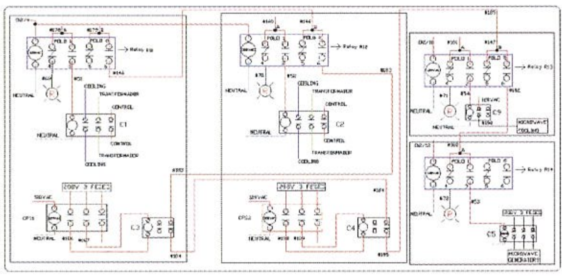

Figure 3: *Detail of the Relay Logic Schematic*

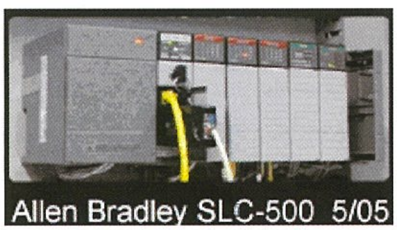

Figure 4: *SLC500-5/05 Controller*

Vacuum Measurement System

Since the stage of operation is determined by the pressure in the plasma chamber, the PLC had to receive feedback from the vacuum gauges. This was not possible with the existing equipment. A new vacuum measuring instrument, compatible with the new controller, was specified to substitute the existing instrument. The vacuum measuring system used was a Varian Multi-Gauge controller, as shown in Figure 5. This equipment has the capacity to connect multiple gauges; it also has an analog output and has RS-485 communication port, as shown in reference [10]. Using serial communications instructions the PLC gathers the value of the pressure from the Multi-Gauge Controller.

Figure 5: *Vacuum Measurement System*

Vacuum Valves

The old manual vacuum valves were changed for pneumatic vacuum valves, as shown in Figure 6. The pneumatic valves are normally closed so the chamber stays at the current pressure if a power failure occurs.

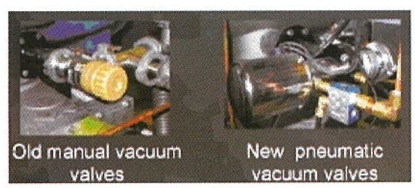

Figure 6: *Pneumatic Valves*

Relay Logic

Logic was developed in relay logic to prevent human errors aiming to ensure the safety of the laboratory personnel and the equipment. Through certain connections made between the contactor relays, some equipment cannot start unless its permissive is enabled. The relay logic can be enabled either by the operator using push-buttons and switches in the control panel, or by the PLC when the control is in automatic mode. The mode is controlled by a main switch that requires a key to prevent undesired switching during normal operation.

RESULTS & CONCLUSION

The automation of PUPR-MC plasma machine has proven to be practical and beneficial to the laboratory operation. Tests performed in manual mode showed that it allows the operator to run the machine very easily, from a single position at the control panel. This has saved time in the experiments process because the operator does not have to manually open or close valves while managing the rest of the equipment. Automatic mode allows the operator to start PUPR-MC plasma machine and dedicate to other tasks while the controller performs all the steps required to produce plasma.

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