PXR Based Vacuum Control for Testing Various Components of SST-1

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Abstract. Vacuum system of steady-state Superconducting Tokamak (SST-1) has a very essential role during SST-1 plasma operation. For this purpose, its data acquisition and control system should be reliable and accurate. The PXI based faster real time data acquisition and control system were used for performing various operations like online data measurements, control, display, status indication in form of graphical visualization and storing the data for future analysis. We developed such PXI based vacuum control and implemented to our ongoing experimental set-up. This paper will describe the detailed information and guidance on PXI based platform for data acquisition and control used during the campaign.

1. Introduction

Vacuum chamber of SST-1 Tokamak [1, 2] comprises of two vessels. One is vacuum vessel and another one is cryostat. The vacuum vessel will be used for the plasma confinement while the cryostat will be used to provide the operational environment for superconducting coils and LN$_2$ thermal shields. The superconducting coils are cooled down to 4.5 K and are charged at 10 kA current for long time. These coils have to be protected from the heat radiation coming from baked vacuum vessel and room temperature cryostat surfaces by using LN$_2$ radiation shields all around them. Apart from this, the cryostat is maintained at a high vacuum $< 1.0 \times 10^{-5}$ mbar in order to prevent the plasma discharge inside the cryostat during operation. Also vacuum vessel is maintained at ultra-high vacuum $< 1.0 \times 10^{-8}$ mbar. Ultra-high vacuum as well as High vacuum can be maintained by applying the reliable pump operation, data acquisition and control system which is possible with proper functioning of vacuum pumps, gate valves and other related vacuum equipments. Hence the faster real time based data acquisition and control system is used for performing various operations such as online data measurements, controlling the various parameters, display, status indication in form of graphical visualization and data stores for future analysis. Such PXI based vacuum system is designed and implemented during the testing of various SST-1 components like TF coils, PF coils and 5 K thermal shields.

2. PXI based Data Acquisition and Control System

Data acquisition systems, as the name implies, are the products and/or processes used to collect information to analyze some phenomenon. The purpose of data acquisition and control is to measure an electrical or physical phenomenon such as voltage, current, temperature, pressure or vibration. PC-
based data acquisition uses a combination of modular hardware, application software and a computer interface to take measurements. PXI stands for PCI extensions for instrumentation, which is a rugged PC-based platform that offers a high-performance, complete system solution for measurement and automation systems. It consists of a central host, remote units and a communications network followed with in-house developed software. It collects data from various sensors located at different places and then stored this data in the local server. At the same time, this data is also shared with main central control, which manages and distributes the data with other sub-systems. The schematic diagram of this PXI Based vacuum control with signal description is shown in the figure 1.

![Diagram](image)

**Figure 1.** The Schematic diagram of PXI Based vacuum control signal description.

The schematic diagram representing the major components of the vacuum data acquisition and control system is shown in the figure 2.
3. System Description
The test facility is developed for testing the various SST-1 components as described earlier. This facility is a large ultra-high vacuum (UHV) chamber having a turbo-molecular pump (TMP), two numbers of Roots pumps, three numbers of electro-pneumatic gate valves, temperature sensors, B-A gauges and residual a gas analyzer (RGA). Using PC based user interface, the complete pumping system is controlled. Also a provision is adapted for the switch over to manual mode in case emergency. TMP has its own hardwired safety interlocks like speed, vibration and temperature parameters to ensure safe operation. Further TMP can also be manually switched ON/OFF from its respective control unit whenever it is required.

The test facility is pumped initially with two numbers of Root pumps. After achieving the pressure inside the chamber < 1.0 × 10⁻³ mbar, Root pumps are isolated by closing their respective gate valves. Once the isolation of Roots pumps is ensured, TMP is used for further pumping by opening its gate valve. Vacuum inside the chamber is monitored continuously and in the event of increase in pressure above the critical limit, the gate valve of TMP will be closed and Root pumps will be switched ON for the rough pumping by opening their respective gate valves to maintain the chamber vacuum. Graphics User Interface of the application software developed in LabVIEW is shown in the figure 3. It shows the status of TMP ON / OFF condition, TMP speed, Roots pumps ON / OFF condition and their respective gate valves OPEN / CLOSE position etc in graphical mode. The coil inlet temperature and LN₂ temperature can be seen here in the graphical mode. Also the vacuum status of the chamber and the pumping line can be seen.
Electro-pneumatic gate valve with its hardwired safety interlocks to ensure minimum required conditions for opening/closing is mounted over TMP for its safe operation. For pressure measurement, monitoring and operation, the number of UHV gauges are mounted into the vacuum chamber and pumping line. Status of UHV gate valves (open/close) is transmitted to vacuum measurement system. A large number of data is generated from different pressure measuring equipments, controller of the pump, valves, temperature sensor connected to the TF coil and RGA during the operation. Data varies in terms of its nature and is used to monitor the functionality of the different equipments. Also it is used to diagnose the reason for malfunctioning of any unit. All the parameters used for the operation and monitoring will be stored in the hard disk for post analysis purpose. Figure 4 shows the vacuum status and control parameters stored in Excel format. Excel format is chosen because of its wide spread availability and user friendly operating environment for analysis and plotting. Also one can easily access the data for a give time and date whenever required. Data acquisition of the vacuum system should be capable to carry out all these functions which can be possible by using PXI bus based Hardware. In front end electronics isolation cards are used to isolate the PXI system from external disturbances like high voltage spikes.

Figure 3. The schematic of Graphical user interface and vacuum status of the test facility.
To ensure uninterrupted operation and measurement, the system is provided with emergency power. Also a battery back up is provided for smooth transition from main power to emergency power in case of interruption. The PXI system [3] is useful to control different components of vacuum system by software programming using interlock logic. Apart from software interlocks, hardware interlocks are also implemented in vacuum system for the safety of crucial vacuum system components like vacuum pump, gauges etc. The PXI system is useful to control different components of vacuum system by software programming using interlock logic. Apart from software interlocks, hardware interlocks are also implemented in vacuum system for the safety of crucial vacuum system components like vacuum pump, gauges etc.

For implementation of hardware interlocks Relay box has been developed. Relay box detects conditions like vacuum pump ON/OFF, speed of pump and accordingly operates the Gate valves. The digital output lines from PXI system are connected to the relay box so that gate valves can be operated remotely by using software. PXI System can be used in both Window and Remote RT modes. In Window mode, PXI controller is loaded with Windows-2000 operating system while in Remote RT mode, PXI system runs on Real time operating system LabVIEW RT. National Instruments LabVIEW with the LabVIEW Real-Time Module and RT Series hardware delivers deterministic, real-time performance for data acquisition and control systems. Window mode can provide a general platform for developing and running any non-critical measurements and control applications. It is not an ideal platform for running the applications that require precise timing or extended up time. It never
follows the program priorities strictly. Also it takes a variable amount of time to respond to a given interruption. While RT mode can be used to run the applications with very precise timing and high degree of reliabilities. The priority of the tasks can be defined using this RT mode. RT mode places the high priority tasks in time-critical codes while the low priority tasks such as storage, network communication etc are placed to a less important codes. Also real-time operating systems guarantee that all interrupts will be performed within a given time frame. Using LabVIEW graphical programming, LabVIEW Real-Time embedded control application is developed and executed the program to run on an independent hardware target. LabVIEW Real-Time targets include an embedded processor running on RTOS, onboard memory and local storage. Currently we have tested all the functions from PXI System in RT mode.

4. Conclusion
PXI based vacuum control for Remote RT modes for remote control of a single TMP, Roots pumps and their respective gate valves for opening and closing is successfully developed and demonstrated during SST-1 components testing. This work will be very useful for SST-1 pumping system automation. The above-developed system is scalable and it can be expanded and integrated for future needs for automation.

5. Future works
In SST-1 Tokamak, twenty one numbers of TMPs, three numbers of Roots pumps, two numbers of Cryo-pumps will be used for pumping purpose. Also a large number of Piezo-electric valves will be used for gas feed. For such purposes, more numbers of channels for these large numbers of TMP ON/OFF, Root pump ON/OFF, respective gate valves OPEN / CLOSE etc will be incorporated for smooth and remote operation of SST-1 vacuum system.

References
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