

Control and data acquisition system for SCR-1 Stellarator

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ABSTRACT

The design and implementation of a small-size modular stellarator's (SCR-1) control and data acquisition system is introduced and discussed in this article. The described development includes the validation and integration of vacuum pumping, gas injection, Electron Cyclotron Heating (ECH), diagnostics, and magnetic confinement systems of the SCR-1.

The control system was implemented on a National Instruments® PXIe® platform. By data flow programming, it was possible to develop different algorithms for the simultaneous execution of four threads during the plasma discharge sequence (device safety, gas injection, data acquisition and plasma discharge), where the primary goal is to implement a robust and secure system considering the integrity and safety of the SCR-1 work team and the hardware involved. Through the implementation of this control and data acquisition system, it was possible to perform the first plasma discharge and, therefore, obtain first data of device operation.

1. Introduction

A small modular stellarator was designed, constructed and implemented at the *Instituto Tecnológico de Costa Rica* with the main goal of providing a tool to carry out engineering and physics research of small size confinement magnetic devices [1]. This was the first device of this technology in Latin America. Stellarator of Costa Rica 1 (SCR-1) is a small-size modular stellarator (Major radius of $R = 247.7$ mm, aspect ratio of 6.2; a low shear configuration with core and edge rotational transform equal to 0.312 and 0.264, a volume of 7.8 liters and 10 mm thickness 6061-T6 aluminum vacuum vessel) [1]. Plasma will be confined in the volume by an axis magnetic field of 41.8 mT generated by 12 modular coils with 6 turns each, carrying a current of 725 A per turn providing a total toroidal field (TF) current of 4.35 kA-turn per coil. This field is electron cyclotron (EC) resonant at R with a 2.45 GHz as 2nd harmonic, from 2 kW and 3 kW magnetrons. SCR-1 was redesigned from UST_1 Stellarator [2]. The operation of the entire device has been divided into 5 subsystems: Vacuum, Gas Injection, Plasma Heating (ECH), Confinement and Diagnostics

2. Development platform

The SCR-1 is composed of a series of commercially available equipment

for industrial use, such diversity of equipment made it necessary to work with different types of interfaces and communication protocols, including: digital inputs at different logical levels, RS-232, RS-485 and analog references. For this reason, for the hardware it was necessary to implement a system for applications of modular control and data acquisition with possibilities for the connection of several communication interfaces. The software required a development environment with facilities for the handling of communication interfaces, the ability to interact with other languages and applications, graphic and textual tools for digital signal processing and real-time programming possibilities.

The laboratory has a PXIe development platform from National Instruments®, specifically an NI-PXIe8135¹ system and different modules for the control and acquisition of signals in the experiments that are performed. A module with 32 inputs and 32 digital outputs, externally powered and optocoupled for industrial logic levels (NI-PXI-6514²), a high-performance 16-port serial interface (NI-PXI-8430³) and 3 modules for acquisition of simultaneous data with analog and digital I/O of different capacities in addition to counters and timers for PWM or A/D (NI-PXIe6363⁴) signals. [3]

Considering the possibilities of control and communication of the equipment at the Stellarator and comparing them with the available resources, it was determined that PXIe development platform complied with the hardware and software requirements that allow it to be used

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¹ For more information and features you can look for the model at <http://www.ni.com/pdf/manuals/373716b.pdf>.

² For more information and features you can look for the model at <http://www.ni.com/pdf/manuals/372199c.pdf>.

³ For more information and features you can look for the model at <http://www.ni.com/pdf/manuals/371332g.pdf>.

⁴ For more information and features you can look for the model at <http://www.ni.com/pdf/manuals/374651d.pdf>.

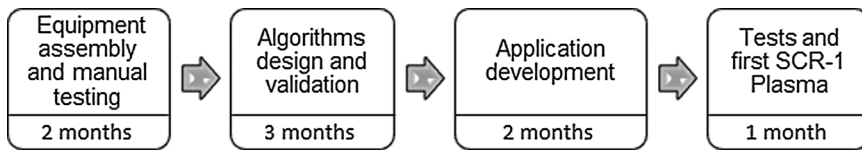


Fig. 1. Development stages for design and implementation of control and data acquisition system of the SCR-1 Stellarator [3].

for the development and implementation of a solution for the control and data acquisition of the device.

3. Development stages

Several stages were carried out during 8 months of work to acquire experience and knowledge about the equipment that make up each of the Stellarator subsystems until the first plasma discharge. Fig. 1 shows the steps followed for the design and implementation of the control and data acquisition system.

All the equipment of each subsystem was installed during the stage of assembly and manual tests; the location of the equipment was performed by analyzing the appropriate position to optimize the space available and free the largest amount of ports at the chamber for future experiments or diagnostics and sensors installation. Tests in this stage were carried out by operating the subsystems manually and individually, from these tests it was possible to develop the operational protocols that contains detailed sequence of operation for each of the equipment including technical aspects, operation parameters and safety aspects.

Software-level implementation was performed using LabVIEW 2016,⁵ from the operation protocols, control and acquisition algorithms were developed for each subsystem and were implemented in different VIs (Virtual Instruments). The purpose of the implementation was to validate the operation of each of the subsystems, check connections to the control modules, measure the ranges and operating conditions, as well as the response of external controllers. Measurements performed during the validation stage allowed to establish restrictions and operating ranges to be considered for the generation of a plasma discharge in the SCR-1.

During the development of the control application two main virtual instrumentation modules (VIs) were designed for the control of the startup stage (vacuum generation) of the Stellarator and another for the execution of the plasma discharge sequence, some safety test were done performing some discharge sequences at the device without heating power and current in the coils in order to test the control and data acquisition system of the SCR-1 Stellarator under different and safe scenarios simulating communication and controllers problems, different sequence parameters and interlocks activation. After the tests, the first plasma discharge at the device was made [3].

4. Subsystems validation

As mentioned in the previous section the first two stages of development were important to gain experience and knowledge in the operation of the equipment that make up the SCR-1.

The vacuum subsystem of the SCR-1 (Fig. 2) consists of a series of pipes, valves, sensors and pumps which allow to generate and measure conditions of high vacuum inside the chamber of the device for the realization of different experiments. The data acquired in different vacuum tests allowed to know the vacuum records of the machine, as well as to identify and repair leaks in the toroidal chamber.

The gas injection subsystem of the SCR-1 has a series of pipes, valves, filters, MFCs and controllers Which allow to carry the working gas from the gas booth to the device for the realization of different

experiments. Fig. 3(A) shows in detail the gas injection subsystem. This is essential because its control allows to approximate the desired gas density values during the realization of experimental pulses, directly influencing the parameters obtained during the discharge [5].

It is widely known that for the injection of gas into experimental devices like Stellarators it is preferred to use piezoelectric valves however, at the beginning of the project only an MFC controller was available. This controller allows regulate the gas flow to a certain extent and kept constant throughout the operation, since by physical restrictions of the device it is not possible to enhance density corrections during the discharge process the design does not include the implementation of a thread for injection of different gas patterns during the discharge [3].

Fig. 3(B) shows the activation states for the gas injection sub-process in the system, once the variables and the amount of gas to be injected (Set-Point/SP) are set the system goes into a waiting state until the activation signal (generated automatically once the operator starts the stellarator discharge sequence) and them, proceeds with the injection of gas for the established period (TG1 & TG2).

Fig. 4(A) shows in detail the components of the Stellarator ECR heating subsystem, the total heating power available is 5 kW at 2.45 GHz distributed in two lines of 2 and 3 kW respectively. Not all components of the heating subsystem of the Stellarator have control and communication possibilities, some of them as tuner must operate manually.

The activation states for ECRH sub-process are shown in Fig. 4(B). The reference signal for the power level (PE) in the magnetron is updated as the parameters for the sequence are set, the device activation signal wait a while (TE1) to inject the microwaves into the system for a defined period (TE2). For safety reasons the operation of this sub-process has as a requisite the field generation in the SCR-1 or the installation of a load that absorbs the microwaves as well as the placement of microwave leakage detectors.

The alternative power subsystem of the SCR-1 corresponds to the set of equipment responsible for establishing but not regulating the working current of the device during a discharge pulse, to generate the magnetic field that confines the plasma. Fig. 5(A) details the components of the subsystem wherein R corresponds to a set resistance to obtain an initial current of 740A.

Fig. 5(B) indicates the activation states for the field generation sub-process in the Stellarator, prior to the activation signal it is necessary to establish the period (TC) during which the relay for the connection of the battery bank must be activated. Additionally, current and temperature sensors ensure safe operation of the subsystem.

5. Application development

At this stage, two virtual instrumentation (VI) modules were designed in LabVIEW, one for the control of the startup stage of the Stellarator and another for the execution of the plasma discharge sequence, this decision was taken based on the execution times of the process, the vacuum process usually takes 20 times longer than the plasma sequence. During the development of the application, all the algorithms proposed in the validation stage were integrated. Subsequent safe control tests were performed to ensure the correct functioning of both modules. Fig. 6 shows the flow chart for the two main VIs.

The implemented systems constitute sequential machines in which the threads related to the operation of the device are executed.

⁵ Using a license owned by "Escuela de Electrónica del Instituto Tecnológico de Costa Rica".

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