# Engineering of the Stellarator of Costa Rica: SCR-1



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# Engineering of the Stellarator of Costa Rica: SCR-1

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**Abstract**. This Paper aims at briefly deSCRibing the challenge of the design and construction of the Stellarator of Costa Rica 1 (SCR-1) [1]. The SCR-1 is a small modular Stellarator for magnetic confinement of plasma ($R_o$=0.238 m, $\langle a \rangle$=0.059 m, $R_o/a$>4.0, expected plasma volume ≈ 0.016 $m^3$, 10 mm thickness 6061-T6 aluminum vacuum vessel) developed by the Plasma Laboratory for Fusion Energy and Applications of the Instituto Tecnológico de Costa Rica (ITCR).

## 1. Introduction

The most challenging part of the design and construction is the vacuum chamber due to its size and its construction. The method of construction included a lot of testing and designing to determine the best way to build it. A second challenge of this construction is the support structure because the small size of the SCR-1 limited the places to fasten the support. During this process a coil support had to be developed, and, in this case, the challenge was obtaining accurately the coil shape. Limited resources to solve all these challenges translated into carefully designing each test.

Designing also needs to take into account the gas injection system. While making this design it is important to preserve the pureness of the gas and of the gas line. In addition, the vacuum pumps are important to the design because the same system will be used on the Spherical Tokamak Medusa [2]. As result, the challenge is to consider the needs of both machines.

Because of the dangerous equipment around the SCR-1, the automation of all of the systems is imperative. To accomplish this, it is necessary to test the equipment. In this case, the challenge is to design a test to make sure the lab staff is safe and that it includes the signals needed for automation; for example, ECH system test and the vacuum pump system test. Coils need a constant current and a constant voltage and the best way to achieve is with an automatic supply control.

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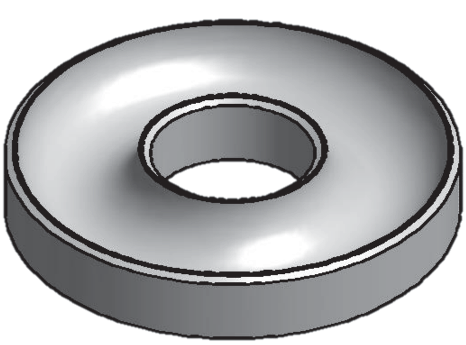
## 2. Mechanical

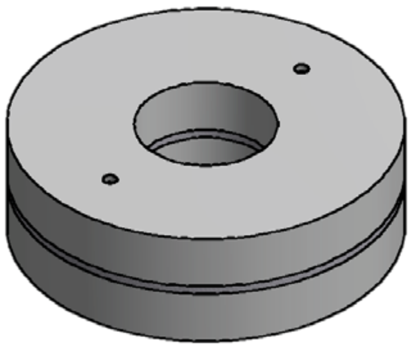
### *2.1. Construction of the vacuum chamber.*

The size of the vacuum chamber is the major issue because the regular methods to build vacuum chambers and the main recommendation cannot be followed either. The first question that we need to answer was regarding which material is the best for the construction. The first answer is stainless steel with 4 elbows at 90 degrees. But for the major radius ($R_0$=238.1 mm) does not fit with the standard elbows and manufacturing 4 customized elbows is too expensive. If two stainless steel plates were used to mill the shape it was more expensive than the elbows. Other option was to use aluminium cast; we could shape it as needed but the workshop couldn’t do a good cast. Finally we decided to use aluminium plates of 6061-T6 and mill the shape of the vacuum chamber.

To make the vacuum chamber, we first mill the half interior shape of the vacuum chamber, as shown in figure 1.a. Then we repeated the process to obtain two halves. After that, the two halves were welded together from the outside as show figure 1.b. However, this have a problem because the torch used to weld the vacuum chamber from the outside didn't fit in the inside of the vacuum chamber. Then the outside of the vacuum chamber was milled, as show figure 1.c. After that, we made all the holes of the vacuum chamber to connect the CF-ports as shown figure 1.D. Finally, the support of the coils was placed and welded. On figure 2 it can be observed how the vacuum chamber is going to look when finished.



A



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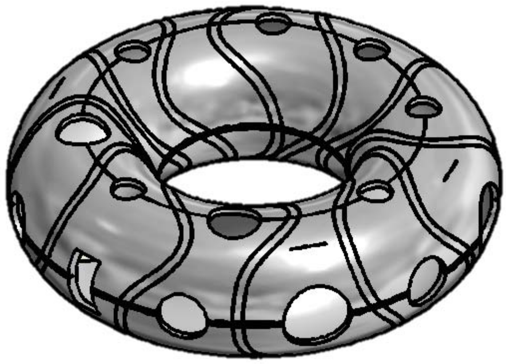

D

Figure 1. A) It shows the interior shape. B) It shows how the two halves are welded with the interior shape. C) It shows how the exterior shape is milled. D) It shows the holes on the vacuum chamber.

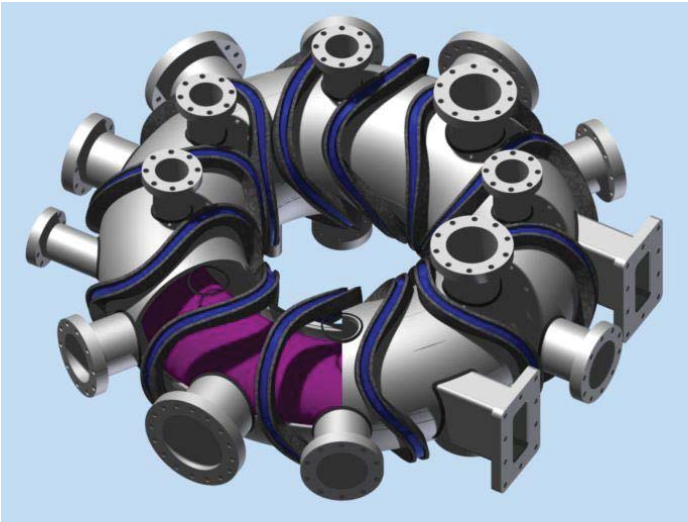

Figure 2. Model in 3D cad of the final version of the vacuum chamber.

With the aluminium ports, it was necessary to find a way to make a CF that its knife does not damage the O-Ring. It was made a test in which in a vacuum chamber made of aluminium cast two ports without the Knife were welded, as shown in figure 3. The port on the right does not have the knife and it uses a fluorocarbon O-Ring, and the CF-port on the left is standard. This test proves we can use this to have a high vacuum. As a result it is better not to have a knife on the aluminium CF port.

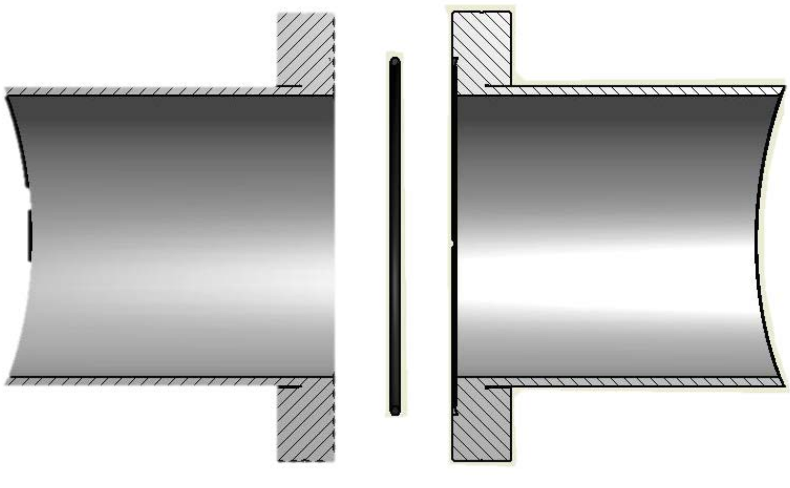

Figure 3. The CF-port without the knife.

### *2.2. Developing the Coils*

To build the coils the major issue was to create the shape and we had three possible ways to achieve this. The first one was to make a cover using a CNC milling machine to make the coil shape but it required a CNC milling machine with 6 axis not available in Costa Rica. Also, this method required a lot of material which in turn increases costs.

The second way was to make the shape using the embossed technique (see Figure 4) but it didn't achieve the expected accuracy, and that was enough to discard the method. The last method was the best and is the one we implemented: to use a 3D printer to develop a casting mold. Figure 5 shows the print version and figure 6 shows the cast and final version of the walls to make the grove. These pieces are going to be welded to the vacuum chamber, using the path marked by a CNC milling machine, that path look like figure 1.D.

With the last method we were able to achieve a precision of ± 0.5mm which is enough for this project.

### *2.3. Gas Injection System*

This system has three lines because one of the lines is for injecting the gas for the main experiment. The second one is for making glow discharges to clean the vacuum chamber, and the last one is for ventilating the vacuum chamber. It is important to mention that it is necessary to keep clean the complete system to avoid the contamination of other gases. That is the reason why we have a vacuum system: to clean the tubes and inject only the gas that we want.

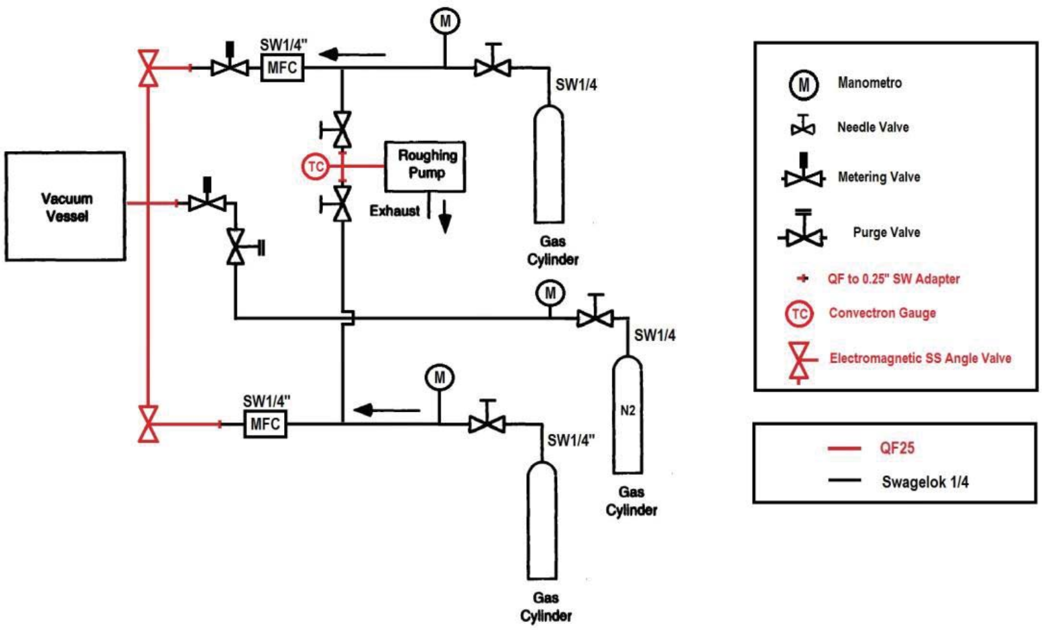


Figure 4. Costa Rica Stellarator 1 gas injection system diagram.

### *2.4. Vacuum System*

The real challenge of the vacuum system was to work on both machines: the SCR-1 and MEDUSA-CR. Figure 5 shows the system and the way it is connected to each machine. They have the same system because our laboratory does not have much space to fit both machines at the same time, and the laboratory has only one mechanical pump and one turbo pump. This system has a vent valve and a gate valve between the mechanical pump and the turbo pump because the turbo pump always needs to be in vacuum, but the mechanical pump can be stopped at any time. On the other side of the turbo pump we have the gauge to measure the pressure and RGA to find leaks on the system.

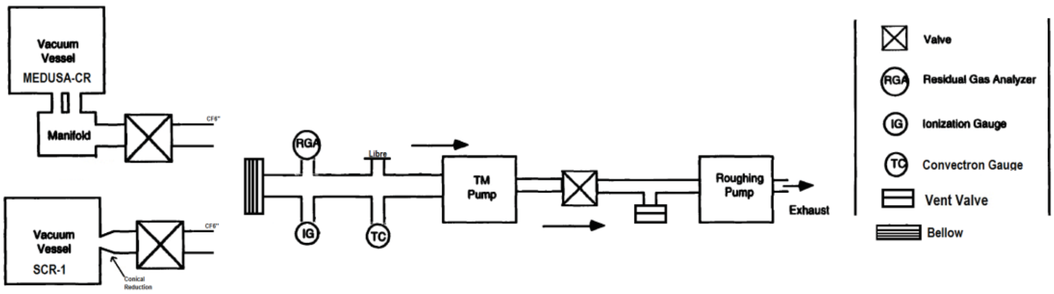


Figure 5. Vacuum system of the SCR-1 and MEDUSA -CR

## 3. Automation System

This aspect is one of the most important on our project because it directly relates to safety. At this moment, we have automatized the vacuum system, the ECH system and the current control for the coils

### *3.1. ECH Automation*

We began the automation of the ECH system with tests. The first test was to connect a load and make some shots to determine how it worked. The second test was connecting the load in a controlled environment, and then make shots like the SCR-1 needs. Figure 6 shows some of the results that are necessary to automate the system; it shows the response time to deliver the power. The next step is to use a PIC to control the two magnetrons with one serial port. We will create a list of commands with a computer or other device like a PXI platform from national Instruments. The design took into count the possible ways to work: the first in which the two magnetrons works as one, and the second way in which each magnetron works separately. This allows the researchers to do different experiments.


Figure 6. System's response time for delivering power

### *3.2. Vacuum system automation*

Similarly to the ECH system, we are using a PIC to control the complete system with just one serial port. Thanks to a list of commands, we can control the complete system through the serial port with a computer or other device like a PXI or NI. The idea of one serial port with each system is to simplify the integration. On this system we will control the mechanical pump, the turbo pump, and the gauges of the system that are on figure 5.

### *3.3. Current control of the coils.*

This system is critical for plasma stability, that is why it is important to have a constant current of 767 A $\pm$2%. In this system, MarteOs will be used to run the application to control an IGBT. This system will be running on a computer; for that reason, the other system will have a serial communication to be able to connect with a PC and in the future allow to integrate everything on one device.

## 4. Conclusion

The construction of the Stellarator of Costa Rica -1 comes with a lot of challenges, mainly regarding the size that its structures and systems need to have. All the manufacture processes are different from a large stellarator, and the limited space between the coils restricts the size and placement of the ports. Finally, the automation is very important in terms of security and to simplify the operation of the machine.

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