Major issues in the design and construction of the stellarator of Costa Rica: SCR-1

J Mora, V I Vargas, L F Villegas, L Barillas, J I Monge and L Rivas
Instituto Tecnológico de Costa Rica
E-mail: jaime.plasma.tec@gmail.com

Abstract. This paper aims at briefly describing the design and construction issues of the stellarator of Costa Rica 1 (SCR-1). The SCR-1 is a small modular Stellarator for magnetic confinement of plasma developed by the Plasma Physics Group of the Instituto Tecnológico de Costa Rica (ITCR). The SCR-1 is based on the small Spanish Stellerator UST_1 (Ultra Small Torus 1), created by Eng. Vicente Queral. These mains issues consist of the size of the Stellarator, closeness between coils, coupling of ECH to the vacuum chamber and the device for support. The size has become a problem because the vacuum chamber does not allow a lot of space to attach diagnosis devices, the heating system, the vacuum system and the very same support of the chamber. As a result of this lack of space, the Stellarator’s coils are placed very close to each other; this means that two of the coils around of the vacuum chamber clash and cannot be placed as designed. The issue regarding the coupling of the ECH (electron cyclotron radio-frequency) to the vacuum chamber comprises the fact that the wave guide with rectangular shape does not match the CF port with circular shape on the vacuum chamber. In addition, the device for supporting the Stellarator has presented a challenge because of its size and the placement of the coils; in other words, there is not enough space between the ports and coils in the Stellarator to place appropriately the device for support.

1. Introduction
This paper deals with the major issues of the construction of the stellarator of Costa Rica (SCR-1). This device is being built by the Plasmas Physics Group of the Instituto Tecnológico de Costa Rica, based on the Spanish Stellerator UST-1 (Ultra Small Torus 1).

Some of the characteristics of the SCR-1 are the following. It will be a 2-field period modular stellarator with an aspect ratio of 6. Low shear configuration with core and edge rotational transform equal to 0.32 and 0.28. This plasma will be confined by a magnetic field \( B \approx 90 \text{ mT} \) given by 12 modular coils with 12 turns each, carrying a current of 725 A per turn providing a total toroidal field (TF) current of 8.7 kA-turn per coil. Typical length of the plasma pulse will be between 4 s to 10 s.

2. Major issues
The main construction issues consist of the size of the Stellarator, closeness between coils, coupling of ECH to the vacuum chamber and the device for support. The size has become a problem because the vacuum chamber does not allow a lot of space to attach diagnosis devices, the heating system, the vacuum system and the very same support of the chamber.

As a result of this lack of space, the Stellarator’s coils are placed very close to each other; this means that two of the coils around of the vacuum chamber clash and cannot be placed as designed.
The issue regarding the coupling of the ECH (electron cyclotron radio-frequency) to the vacuum chamber comprises the fact that the wave guide with rectangular shape does not match the CF port with circular shape on the vacuum chamber. In addition, the device for supporting the Stellarator has presented a challenge because of its size and the placement of the coils.

2.1. Coils clash
The clash of coils is a result of previous simulations of heating of coil cord [1] which prove that for the SCR-1 coils of 6 wires with 1088 A (see figure 1) cannot be used to sustain a discharge of 10s duration. This forced the reduction of the current and the increase of the amount of turns per coil; a total of 12 turns per coil with 725 A. However, the size of the coils was not considered for it would produce a clash between them avoiding the construction of the device.

To solve this it was proposed to use wire to coil motors to accommodate better the coils and by doing so reducing their size. In addition, the coils will be rotated one degree, to reduce the clash (see figure 2). Then, the associated simulations are done and confirmation that the field lines remain closed is obtained [2].

2.2. Connection of the ECH system to the vacuum chamber
The heating system ECH (2.45 GHz) for the SCR-1 forces to reduce the rectangular area of the WR340 waveguide to connect it to the circular viewport in the CF port, trying to reduce loses and allowing the wave to travel through the waveguide to the toroidal chamber. There are three possibilities under analysis: (1) Locate in the market a transition of WR340 waveguide to circular (see figure 3); (2) Use a system with Adapter WR340 Waveguide to Coax and antenna; or (3) locate a port with the WR340 shape in the vacuum chamber and vacuum windows for microwave with WR340 waveguide shape.

For option 1, it was identified a transition of WR340 waveguide to circular of 85 mm; to that end it was located a CF port of 6” and a viewport of 89 mm of visible area. The quartz viewport was selected because this material allows the passing of microwaves and supports the power of the ECH (5 KW). Besides this material, the possibility of using sapphire was under study because it also supports the work conditions; nevertheless, sapphire greatly increases costs and, therefore, is discarded. The other two options were discarded due to the fact that the first option solved the problem.
2.3. Space to place the vacuum ports
The space between coils limits the size of the ports that can be placed. The maximum CF allowed size for the SCR-1 is 6 inches. To reduce the distance between the vacuum pump and the toroidal chamber, a vacuum port was placed on the bottom. Initially, a CF port of 6 inches was considered to be placed but due to the reduced space to perform the lines for coils it was changed for a CF port of 4 ½ inches. This only affects the molecular conductance of the system.

The CF port of 6 inches makes difficult to do the lines for the coils with a milling machine (see figure 4). This presents a challenge because the coils will be made with a CNC milling machine. As observed in figure 5, there is more room for the milling machine to move and do the canals for the coils.

2.4. Space between coils to place ports
The space between coils limits the placement of ports and it is important to guarantee that any port is placed on top of the coils. Ports must be away from the coils to place correctly the coils. The placement of the viewports is a challenge. As shown in figure 6, viewport 1 barely allows seeing the
interior of the stellarator. Also viewports 2 and 3 allow seeing more details within the vacuum chamber but without the desired vision range.

The solution is to look for the appropriate and easy placing of these ports to allow a useful vision range, the current placement of the visual ports allows seeing the ports in which the diagnostics will be placed. These diagnostics include the Langmuir probe enabling to see when the probe enters the plasma. Also, the placement of those ports is to enable seeing the 6” ports in which the experiment of mapping surfaces will be used.

![Cross-section view of the vacuum chamber](image)

**Figure 6.** Cross-section view of the vacuum chamber that shows the vision range of the ports.

2.5. Vacuum chamber support

The reduced size of the SCR-1, with an outer diameter of the toroidal chamber of 75.06 cm, and the little space between coils make it difficult to locate support points and equipment as the vacuum pump. To solve this, a special support was designed.

This design allows having a removable work area around it in case that equipment needs to be placed in this space.

Besides that, the support will be screwed to the table with protruding edges at the bottom of the vacuum chamber. These edges will be screwed to the support on the points signaled on figure 7. In addition, the support points are open to leave space for the vacuum chamber and provide more stability to the table. Also, the support for the Langmuir probe was designed so that it does not interfere with other equipment as shown in figure 7.

3. Conclusions

The construction challenge of a small stellarator constitutes that the space on the vacuum chamber is limited and makes it hard to manipulate all the equipment around the stellarator. The big difference between designing a normal stellarator and a small stellarator is that with the big one there are many spaces between coils to place ports. The SCR-1 has 16 ports which limited the amount of diagnostics that can be placed on it.
Figure 7. Group of supports for the SCR-1 and support of the Langmuir probe in its final position.

References
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