CHARACTERIZATION OF TURBULENT TRANSPORT OF PARTICLES, OPTIMIZATION OF PLASMA HEATING AND OPERATION CURRENT CONTROL IN THE COILS OF THE SCR-1 STELLARATOR

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1.INTRODUCTION

The SCR-1 stellarator, operational since June 2016, has emerged as a pioneer in Latin America in the field of modular stellarator devices, developed by the Costa Rica Institute of Technology. This device has been the subject of continuous characterization and optimization efforts, with a focus on significant improvements in turbulence, coil feeding and wave propagation within the SCR-1 stellarator. This work presents a first study of turbulence, examining behaviour at the plasma edge and its interaction with external electric fields, as well as the importance of electrode polarization. In addition, the design of the DC-DC Buck converter for the SCR-1 current coil control system is addressed, along with the proposal of a Vlasov antenna to optimize energy deposition in the plasma. Results indicate the significant influence of electrodes on plasma behaviour. A power converter was designed to ensure an efficient and safe electrical supply and simulated by PLECS. The buck converter was deemed crucial for precise and stable current regulation in the coils. Electronic components were sized to handle the required current and voltage specifications. Finally, a modified Vlasov antenna was designed, which demonstrated in COMSOL Multiphysics simulations that the new configuration improved the distribution of electromagnetic waves in the SCR-1 vacuum vessel.

The SCR-1 corresponds to a two-field period modular stellarator with a major radius $R = 247.7$ mm, an aspect ratio $= 6.2$, it has a low-shear magnetic configuration ($\iota_o = 0.312$ and $\iota_a = 0.264$), its vacuum vessel is made of 6061-T6 aluminium, it has 12 modular coils with six turns each, with a current per turn of 725 A, which allows a toroidal field (TF) current of 4.35 kA-turn per coil ($\langle B \rangle = 41.99$ mT). The coils are powered by a 120 V cell battery bank and the plasma is generated by two magnetrons providing 5 kW (2.45 GHz), corresponding to the second harmonic ($B = 43.8$ mT). The plasma pulse has a duration of 4-10 s and a minor plasma radius of 39.95 mm (plasma volume $= 0.0078$ m^3) with a line-averaged electron density of $5 \times 10^{16}\ m^{-3}$ and an electron temperature of 6-14 eV [1].

2. PLASMA TURBULENCE IN THE SCR-1 STELLARATOR

For plasma turbulence measurements, an electrode was necessary to generate an external electric field. Significant observations were made regarding the impact of electrode introduction on plasma behaviour in the SCR-1 stellarator. The changes in ion saturation current were consistent with expectations; specifically, negative polarization led to a reduction in this current near the Last Closed Magnetic Surface (LCMS) and SOL, suggesting a lower electron density, as shown in Fig. 1.a. Although the radial variation was not mapped, preventing the determination of the SOL width, the flux values provided a reliable indicator for identifying where to continue mapping the region's width.

The radial velocity at $R = 0.2905$ m, as shown in Fig. 1.b, decreased markedly upon electrode introduction. A similar reduction was noted at $R = 0.3070$ m, a position closer to the last magnetic flux surface. Moreover, the poloidal velocity and electric field, illustrated in Fig. 1.c and Fig. 1.d, exhibited a similar trend both with and without the influence of the electrode. However, during the critical phases of plasma discharge, between 1.5 s and 2.5 s, higher average values were observed, indicating maximum confinement during this period. The inclusion of the electrode resulted in a significant decrease in radial particle flux near the plasma, the generated electric potential enhanced the effective radial velocity of charged particles. Furthermore, the electrode potential at

-120 V was observed to reduce radial flux, although less significantly than at -60 V. Similar conclusions to those of our results were presented in [2].

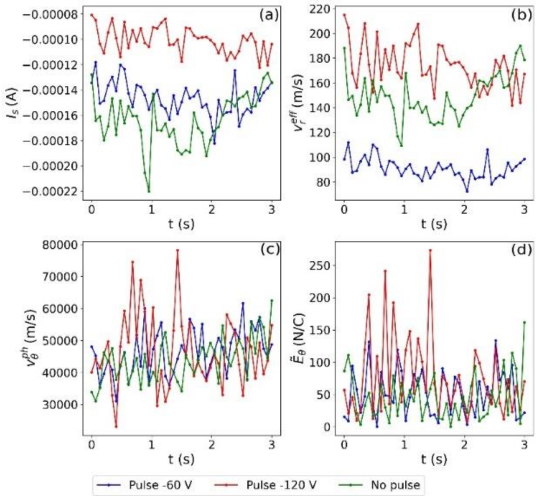

Fig. 1: (a) Saturation ion current, (b) radial effective velocity, (c) poloidal velocity and (d) poloidal electric field in function of time for the radial position R = 0.2905 m.

3. CONTROL COILS CURRENT FOR THE SCR-1 STELLARATOR

Using the *PLECS* software, the proposed design for the circuits of the stellarator SCR-1 coil current control system was successfully verified. Regarding the full-wave rectifier, an AC input with an RMS voltage of 120 V was applied. The diode rectifier operated as expected, converting the AC signal into a pulsating DC signal. It was demonstrated how the capacitor smoothed the rectifier output, significantly reducing voltage ripple and improving signal stability. Proper filtering is essential to minimize fluctuations in the output voltage of the Buck converter. The voltage ripple of the rectifier circuit is approximately 1.5 V, equivalent to 0.5 % of the input voltage. For the Buck converter circuit, shows that the average stabilized current is 725.012 A, with a ripple of 15.642 A, corresponding to 2.16 % of the inductor current. Both values are suitable for the intended application. Additionally, the stabilization time of the circuit is approximately 0.02 s, which is acceptable for the stellarator application, where the discharge cycle is 8 s. The voltage at the SCR1 coils displays the voltage value set to achieve the coil operating current, which also stabilizes within a very short period 0.02 s.

4. VLASOV ANTENNA FOR THE ECRH SYSTEM

Using COMSOL Multiphysics software, a comprehensive simulation of SCR-1 was developed, integrating modules such as the electromagnetic wave module for the heating system and the laminar flow module for gas injection. By comparing three cases, a parametric sweep revealed that the modified cut case (45 °) improved the maximum electric field magnitude by up to 8 %, while the bevel-cut case improved it by 9 % with an angle of 81.4 °, compared to the scenario without an antenna. This adjustment facilitated a more even spatial distribution. The reduction in wave reflection through the same port in the bevel-cut configuration contributed to these outcomes. Considering the geometry of the SCR-1 vacuum vessel, the optimized angle ensures a more uniform wave deposition within the SCR-1 vacuum vessel. The successful implementation of the 3D model of the SCR-1, including the parameterized Vlasov antenna with adjustable cutting angles, enabled the visualization of electromagnetic wave deposition within the SCR-1 by examining the electric field magnitude across different antenna configurations.

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