The Trapped Electrons Experiment T-REX

F. Romano*, P. Giroud-Garampon, J. Loizu, M. Nöel, S. Antonioni, J. Genoud, D. Mykytchuk, J.-P. Hogge, and M. Podestà
École Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland.
(*francesco.romano@epfl.ch)

Gyrotrons are essential devices for electron cyclotron resonance heating (ECRH) in magnetic fusion reactors, and need to deliver MW-level power continuously and reliably. However, experiments have revealed that undesired trapped electrons in the magnetron injection gun (MIG) region, can cause to internal damages due to arcs, and large electron currents that its power supplies cannot withstand. Currently, tight manufacturing tolerances are required for the MIG geometry [1], making their manufacturing costly. Understanding the physical principles behind such phenomena could allow relaxing these tolerances. To address this, we have a novel and unique plasma experiment named "the TRapped Electrons eXperiment" (T-REX) has been established at the Swiss Plasma Center of EPFL. It is designed to investigate the physics of trapped electron clouds in gyrotron MIGs [2].

T-REX can replicates the electric and magnetic fields and geometries of a MIG, and it is supported by 3D Particle-in-Cell (PIC) simulations with the FENNECS code [3–6].

The T-REX setup is composed by two coaxial electrodes - with a specific geometry that ensures the formation of trapping potential wells - installed in a vacuum chamber sitting on top of a superconducting magnet. The central electrode is biased to negative DC voltages and the outer one is at ground, creating a radial electric field up to $2\,\mathrm{MV/m}$ and an axial magnetic field $B < 0.4\,\mathrm{T}$. This setup mimics the principle of Penning-Malmberg traps. The electron cloud forms spontaneously once a certain voltage threshold is reached. The electrons are trapped in the potential well and rotate azimuthally very fast due to the $\vec{E} \times \vec{B}$ leading to the creation of even more electrons by ionizing the residual neutral gas.

The T-REX experiment is equipped with multiple diagnostics. Currently, time-resolved (kHz) current measurements of the main experiment components are performed, as well as optical emission spectroscopy (OES) to attempt extracting local electric and magnetic field via Stark and Zeeman effects. Also available is streak camera imaging (GHz) to observe cloud dynamics. Finally, a system of 32 planar current probes has been installed at the top of the electrodes assembly to measure radial and azimuthal electrons distribution, but also to detect fast rotating structures, having 3-7 probes with a cutoff frequency of 1 GHz, and the rest in the 100s of kHz to still measure plasma oscillations.

Currently, we have remarkable agreement between experiments and simulations in terms of the magnitude of the observed currents and the threshold in $\vec{E}$ and $\vec{B}$ fields for the spontaneous formation of the electron cloud. We also found that 3D simulations are required to fully simulate the physics of trapped electron clouds in coaxial geometries. In particular, we found the crucial role of the diocotron instability, as it directly influences the spatial repartition of the currents and their bursty dynamics.

The results of T-REX and FENNECS provide new understanding on nonneutral plasmas in conditions mimicking those of a real gyrotron MIG and prepare the way to enhance gyrotron performance and reliability in fusion energy systems.

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