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Final results of the Phase-1 of the PROTO-SPHERA experiment and first evidences of plasma tori production and sustainment

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The PROTO-SPHERA experiment is an unconventional magnetic confinement scheme, which aims at producing a Spherical Torus (with $I_e \leq 300$ kA) around a Plasma Centerpost (with $I_e = 70$ kA) fed by electrodes of annular shape, in contrast with the metal centerpost of conventional Tokamaks. The Phase-1 of PROTO-SPHERA, aimed of obtaining a stable Hydrogen Plasma Centerpost, lasting 1 sec at $I_e = 8.5$ kA longitudinal current level, was successfully ultimate at the begin of 2018. The line averaged plasma electron density on the equatorial plane of the Plasma Centerpost increases linearly with I_e and reaches, at $I_e = 10$ kA in Argon, the considerable value of $\langle n_e \rangle = 4 \cdot 10^{20} \text{ m}^{-3}$, similar to what is obtainable today only in high-field Tokamaks, while in Hydrogen the still respectable value is $\langle n_e \rangle = 1.5 \cdot 10^{20} \text{ m}^{-3}$ at $I_e = 10$ kA; spectroscopic measurements show very pure plasma when we operate in Hydrogen (Balmer lines only), and Langmuir probe measurement show an edge temperature of 4-8 eV and an edge density of few 10^{19} m^{-3} in proximity of the anodic plasma when we operate in Argon. The Plasma Centerpost show a strong toroidal rotation, due to $E \times B$, that prevents any anode anchoring. During the spring/summer 2018 the kink destabilization of the PROTO-SPHERA Plasma Centerpost and the plasma tori production has already been preliminarily obtained in the actual Phase-1 of the experiment, by adding 4 impromptu vertical field external PF coils, that are wound outside the vacuum vessel and fed in series with a new power supply based on SuperCapacitors. The result in Hydrogen has been a disruption-free coupled configuration, obtained with stationary poloidal magnetic field, in which a very high aspect ratio ($A = R/a \approx 7$) and very high elongation ($\kappa \approx 3$) torus of approximately $I_{ST} \approx 7$ kA is sustained by Helicity Injection, with MHD bursts with a periodicity of ≈ 3 ms, around the $I_e = 10$ kA Plasma Centerpost until the DC voltage VPC between electrodes is turned on, i.e. for more than 250 ms. In 2019 the PROTO-SPHERA experiment has been largely modified: a new insulating/transparent vacuum chamber in PMMA substitute the START Aluminum vessel and 6 internal PF coils has been inserted inside the machine. A "Phase-1.5" campaign is now in progress with the aim to produce/sustain, still at the $I_e = 10$ kA level of Plasma Centerpost current, an elongated ($\kappa \approx 2$) low aspect ratio torus ($A \leq 2$) with a current of the order of $I_{ST} \approx 20$ kA and a volume of the closed magnetic surfaces greater than 50%.

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