
High density helicon mode triggered by current injection

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Résumé

Radio-frequency helicon sources are commonly used to generate high-density, low temperature plasmas. They usually display three modes of operation: a capacitive mode at low radio-frequency power (P_{rf}), an inductive mode at intermediate power and a wave-sustained (W) mode, above a critical power P_c . The W-mode is reached when the plasma density allows solutions for the dispersion relation of the natural helicon/Trivelpiece Gould (W) modes, which depend on the antenna design and the plasma cavity geometry. A large plasma density jump is observed at the transition to the W mode. A strong hysteresis is usually observed, and high-density natural W-modes are observed in the ramp-down, when P_{rf} is further decreased.

We demonstrate here a strategy to trigger W-modes well below the natural critical power P_c , when a small electron current is transiently injected on-axis. When current injection is stopped, the radio-frequency source maintained at P_{rf} smaller than P_c sustains the high-density natural W-modes observed during the ramp-down. A thorough experimental characterization of spatially-resolved plasma density and wave magnetic fields structure is detailed for a half-helical antenna in a 1 m long, 20 cm in diameter plasma vessel, operating in the range of 0.1 Pa and with a static magnetic field of a few hundreds of Gauss. We stress here that a few tens of Watts of DC current injection allows to trigger a W-mode at $P_{rf} = 500$ W (i.e. $0.5 P_c$).

The underlying mechanism lies in the modification of the density profile, which is more centrally peaked in the presence of current injection, and modifies the wave coupling. This mechanism has been validated using the HELIC code, which solves Maxwell's equations with boundary conditions for a given plasma density profile and antenna design. The computation of the absorbed power using experimentally informed plasma density profiles demonstrates that high density W-modes are triggered at lower P_{rf} in the presence of peaked profiles. In this simplified model, the predicted steady-state working points reproduce the experimental features. When injection is stopped, the high density in the cavity allows the sub-critical natural modes to be maintained. These results potentially open new avenues for the development of efficient helicon sources at low radio-frequency power.

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