Seminar

Institute for Plasma Research

Title: Design and Installation of an Improved Pre-Ionization System and Edge Fluctuation Dynamics Studies during Plasma Current Ramp-up in ADITYA-U Tokamak

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Abstract

Ensuring reliable plasma startup and controlling edge instabilities are key to improving tokamak performance and advancing fusion energy development. In the ADITYA-U tokamak, a novel electrodeassisted filament pre-ionization system has been developed to enhance plasma breakdown reliability and improve startup conditions. Unlike conventional filament-based systems—where emitted electrons remain localized near the vessel wall due to the toroidal magnetic field—this advanced configuration employs two biased electrodes mounted on a ceramic base, with filaments positioned in between to emit electrons prior to the plasma discharge. The applied high-voltage bias establishes a strong local electric field that, in conjunction with the toroidal magnetic field of the tokamak, generates an E × B drift, which pushes the electrons deeper into the plasma vessel. This mechanism significantly enhances seed electron penetration, minimizes wall losses, and boosts pre-ionization efficiency. COMSOL-based optimization of the electrode geometry confirms improved electron transport, thereby reducing the required loop voltage and facilitating more reliable plasma initiation in ADITYA-U. The system has been vacuum-tested and ready to be installed in ADITYA-U tokamak along with other accessories such as power supply etc.

Apart from the above-mentioned development work, edge plasma dynamics during the plasma current ramp-up phase reveal intermittent, filamentary bursts characterized by sharp Hα emission peaks along with correlated fluctuations in magnetic field and plasma density. These events occur once the current ramp rate exceeds a critical threshold (~3 kA/ms), linking rapid plasma motion to edge instability onset. Probe measurements identify outward-propagating, interchange-like filaments with radial velocities around 100 m/s, characteristic of turbulent cross-field transport in the scrape-off layer. Spectral analysis indicates lowfrequency (~0.75 kHz) drift–interchange-like modes with distinct phase lags between floating potential and density signals. Statistical analysis reveals non-Gaussian, heavy-tailed distributions with strong skewness and kurtosis, consistent with stochastic filament ejection. Edge gas puffing appears to suppress these bursts through local cooling and plasma column stabilization, although the stabilization mechanism requires further investigation.

Together, these studies establish a comprehensive framework for improving plasma breakdown and current-ramp phase's reliability and understanding the edge turbulence during current ramp-up. In near future, the experiments with new advanced pre-ionization system throwing seed electrons well inside the vacuum vessel to facilitate breakdown with lower loop voltage in ADITYA-U will be conducted. The understanding of edge dynamics will significantly advance startup efficiency and confinement stability in tokamak plasmas—representing a key step toward robust operation in next-generation fusion devices.