Recent Progress in High Poloidal Beta Scenario Development on DIII-D


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The high poloidal beta (βp) scenario has many features that make it a promising candidate scenario for a future steady-state fusion reactor, including: high confinement at low plasma rotation, low disruption risk, compatibility of high core performance with divertor detachment, low transient heat loads on divertor, low inductive current fraction, and high minimum safety factor, leading to no sawteeth and no 2/1 mode.

Conceptually, the high βp approach to a steady-state tokamak reactor was first proposed by Kikuchi in 1990 [1]. Experimentally, high βp plasmas with density Greenwald fraction (fGw) up to ~1.0 and H98y2>1.0 were first obtained in JT-60U. These experiments also had low momentum input, albeit transiently and usually operated at low absolute density [2]. Since 2013, joint research activities by the EAST and DIII-D teams have explored this scenario in both tokamaks, and extended it to key reactor ingredients, as shown in Fig.2.

Figure 1. (a) Electron temperature profiles; (b) toroidal rotation profiles. Experimental data points and their error bars are shown in the same color as the fitted profiles.

The latest DIII-D experiments have extended the high βp scenario to higher performance, meeting the required normalized fusion parameters for ITER Q=5 steady state operation. Plasmas with H98y2≥1.5 and βp≥4 have been achieved at qmin≥2 and β1≥3% and sustained for a current diffusion time before evolving to an MHD-unstable state. The normalized fusion performance $G_{98}=H_{98}\beta_{p}/q_{95}^2$ in these experiments reaches the value predicted in ITER high βp Q=5 modeling [8]. Strong internal transport barriers lead to a high confinement core with bootstrap current fraction ≥80% and line-averaged density at the Greenwald limit. These results confirm the high βp scenario as a highly promising candidate scenario for future fusion reactors.

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References


Figure 2. Growth rate of the leading micro-instability (kinetic ballooning mode, KMB) identified by CGYRO, vs. magnetic shear and pressure gradient at $p=0.6$ of experimental equilibrium at 2.75 s marked by yellow star. Discharge evolution (purple dots, from 2.4 s on the top left to 4.0 s on the bottom right) shows decreasing shear, from detachment driven pedestal deterioration, leads to stronger pressure gradient around the KMB instability mountain.