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Extended Advanced Tokamak Operation with Infrequent ELMs

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Advanced Tokamak (AT) operation strives for high β, improved confinement, and a large, well-aligned bootstrap current in order to achieve a compact steady-state tokamak configuration. While many AT characteristics have been demonstrated, the duration of sustained performance has been limited to a few energy confinement times, generally because of evolving pressure or current profiles and eventual MHD instability. Recent DIII-D experiments have explored methods for extending AT duration. Of particular interest are discharges with an ELMy edge, which are inherently steady-state and provides good edge confinement.

In a recent set of experiments, a new regime was observed when performance equal to ELM-free regimes such as VH-mode is sustained through many low-frequency ELMs. As shown in Fig. 1, β_N~3.8 and H_{98y}~2 ($\beta_N H_{98y}$>6) are sustained for 1 s.

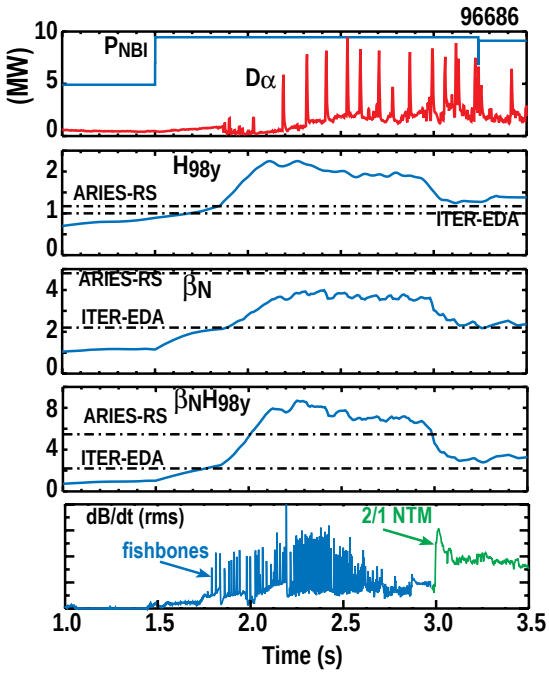

Fig. 1. *Time evolution of high performance discharge with infrequent ELMs.*

Note that this discharge exceeds the ARIES-RS requirement for the $\beta_N H$ product. The q profile is monotonic with q_0~1, and 1/1 fishbones (but no sawteeth) are present throughout the high performance phase. Some parameters of interest during the high performance phase are: β_t~4.5%, n_e/n_{Gr}~0.5, q_{95}~4.4, t_{th}~0.21 s, and f_{bs}~50%.

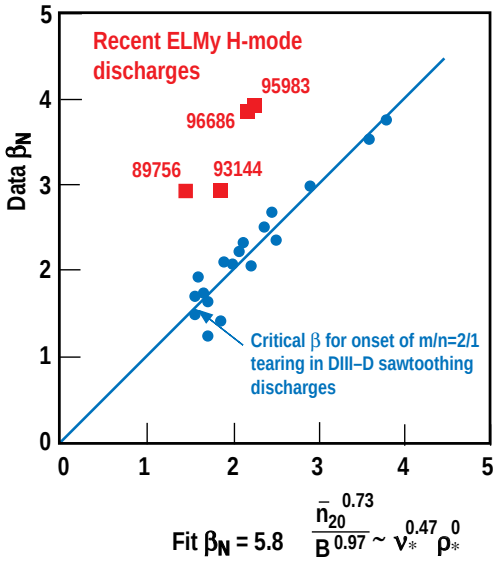

Fig. 2. *The beta limit for improved performance ELMy H-mode (squares) exceeds the NTM limit established for sawtoothing discharges (circles and line) by a factor of 2.*

The key elements required for access this regime are still under investigation, but the operational characteristics include a unique shape (δ=0.77, κ=1.85, single null, with the X-point at the top and the ∇B drift down), a fast current ramp that provides early magnetic shear reversal, and higher recycling near the X-point, We are investigating the possibility that this combination of features modifies the edge stability.

The high performance phase is terminated by the appearance of an m/n=2/1 mode that is believed to be a neoclassical tearing mode (NTM). Figure 2 shows that the β limit at which NTMs are excited in these discharges is significantly higher than the previous limit established in sawtoothing, lower triangularity ITER-shaped discharges. The higher β limit is most likely due to the absence of sawteeth, which provide the seed island trigger. In discharges like that shown in Fig. 1, the NTM appears to be triggered by fishbone bursts or, in some cases, ELMs. Despite the success in increasing the NTM β limit, these MHD modes continue to limit β, limit the pulse length, and adversely affect discharge reproducibility.

Future work will focus on improving our understanding of the edge stability properties of this regime and on developing techniques to suppress or stabilize the NTM. To improve AT characteristics further, somewhat higher β_N (~4.5) with higher q_{min} (>1.5) is needed to increase the bootstrap fraction.

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