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Wide-pedestal grassy-ELM regime using edge-resonant magnetic perturbations in the DIII-D tokamak

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Resonant magnetic perturbations (n=3 RMPs) are used to eliminate large amplitude ELMs and reduce the amplitude of grassy-ELMs in DIII-D plasmas relevant to the ITER steady-state mission. Fully non-inductive discharges in the ITER shape and pedestal collisionality (≈ 0.05-0.15) are routinely achieved in DIII-D with RMP controlled ELMs. The residual grassy-ELMs deliver a low peak heat flux to the divertor, within 50% of the time average heat flux, in plasmas with sustained high H-factor (H98y2≈1.2). These grassy-ELM plasmas have a naturally wide pedestal that is typically 10% of the poloidal minor radius and exceeds the EPED model prediction of the pedestal width by ≈50%. The operating window for RMP grassy-ELMs is in the range required for a steady-state tokamak reactor, such as q_{95} between 5.3 and 7.1, and co-Ip neutral beam torque from 8 Nm down to below 1 Nm. Only small amplitude RMPs are necessary to access this regime, consistent with the large amplification of the RMP by the plasma, typically 3-4x the amplification produced by ITER baseline plasmas, due to the higher beta. Cyclic pulsations are observed in the pedestal profiles and plasma magnetic response, indicative of a dynamic competition between resonant field penetration and flow screening. At the peak of n=3 resonant field penetration the pedestal moves deeper into the stable region for peeling-ballooning modes and the grassy-ELMs are strongly mitigated or suppressed altogether. The use of low amplitude edge-resonant magnetic perturbations to achieve enhanced grassy-ELM performance over a wide operating window and with weak confinement degradation opens the possibility for further optimization of the steady-state tokamak by improved coupling between external fields and natural modes of the plasma. This work is supported by the U.S. Department of Energy, Office of Fusion Energy Science, under DOE contract numbers DE-AC02-09CH11466 and DE-FC02-04ER54698. The experiments described herein were performed on the DIII-D National User Facility operated by General Atomics in San Diego, CA for the U.S. Department of Energy.

References

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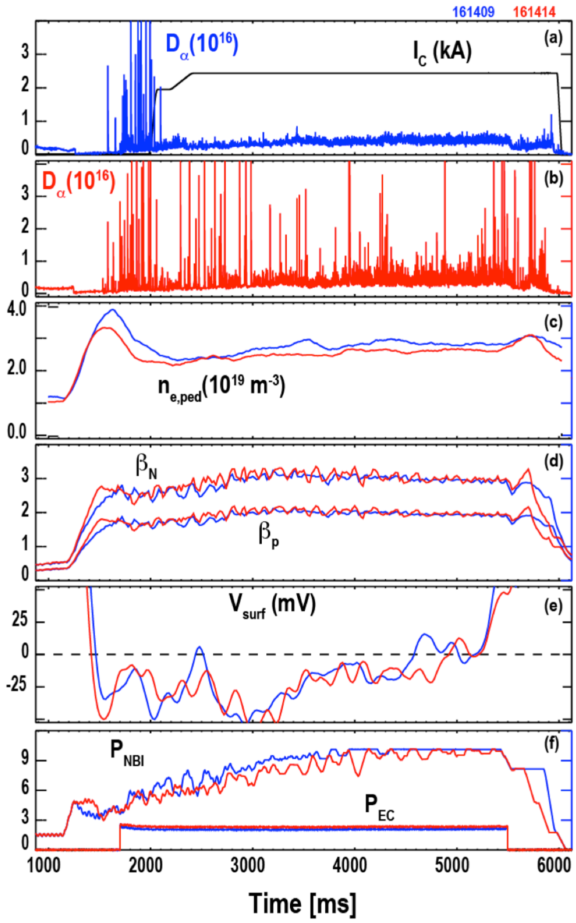

Figure 1. For two fully noninductive plasmas, with (shot #161409) and without (shot #161414) the applied n=3 RMP: (a) Dα signal from the inner-strike-point showing controlled grassy-ELMs for the n=3 RMP case (blue) with 2.5 kA odd-parity I-coil current (black), (b) Dα signal for the no-RMP case (red) showing mixed ELM activity, (c) pedestal electron density $n_{e,ped}$ for the RMP (blue) and no-RMP (red) plasmas, (d) β_N and β_P, (e) surface voltage V_{surf}, and (f) beam power P_{NBI} and electron cyclotron heating power P_{ECH}. Relevant discharge parameters are: plasma current I_P=0.95 MA, toroidal field B_T=1.7 T, average triangularity δ=0.55, noninductive fraction f_{NI}≈100%, pedestal collisionality ν_{*e_ped}≈0.1, β_N≈3, β_P≈2, P_{NBI}≈6.0 MW, P_{EC}≈3 MW, H98y2≈1.2-1.3.