Suppression of Large Edge Localized Modes With a Resonant Magnetic Perturbation in High Confinement DIII-D Plasmas*

EX-D

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Large Type-I ELMs are suppressed with an edge resonant magnetic perturbation in high confinement plasmas [1,2] using n=3 dc currents in the DIII-D I-coil. The magnetic perturbation resonates strongly with plasma flux surfaces across most of the pedestal region $0.9 \leq \psi_N \leq 1.0$ creating remnant islands surrounded by weakly stochastic field lines. The amplitude of the currents required to eliminate all but a few isolated ELM-like impulses during an I-coil pulse is less than 0.4% of I_p. The stored energy, β_N and H-mode quality factor are unaffected by the perturbation field. The electron pressure profile, radial electric field and poloidal rotation across the pedestal are also unaltered along with the H-mode transport barrier. Since large Type-I ELM impulses represent a severe constraint on the survivability of the divertor target plates in future fusion devices such as ITER [3] a proven method of eliminating these impulses is critical for the development of tokamak reactors. Results presented in this paper suggest that a relatively simple set of coils may provide a promising option for controlling ELMs in ITER.

A comparison between two identical discharges with and without an I-coil pulse is given in Fig. 1. The I-coil pulse, shown in (a), suppresses large Type-I ELMs within one ELM cycle (~15 ms) as illustrated in (d). The ELMs are replaced by an increase in magnetic field and density fluctuations. These fluctuations have a distinct bursty and/or intermittent character and are modulated by a 130 Hz oscillation with a 2 ms quiet period followed by a 6 ms active period. In the reference discharge (c), the average energy lost from the pedestal

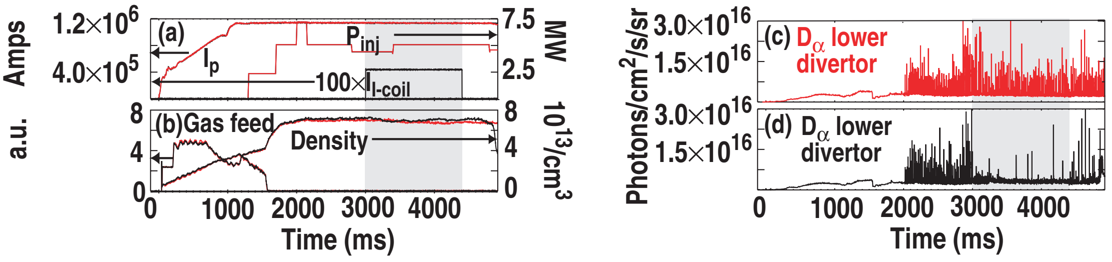

Fig. 1. (a) Plasma current and injected NBI power with (b) density and gas feed for a discharge without (c) and with (d) an I-coil pulse (gray band).

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during a Type-I ELM is 15 kJ. This energy is lost within the first 200 μs of the ELM crash resulting in an impulsive energy source of 1.1×10^{6} J/s$^{1/2}$. During the ELM suppression phase, the pedestal energy drops no more than 5 kJ and typically less than 1 kJ during the 6 ms active period of the oscillation. This results in a maximum impulsive energy source of less than 4.5×10^{4} J/s$^{1/2}$ or a factor of 24 reduction in the largest events compared Type-I ELM impulses.

The ELM suppression is a resonant effect that depends on q_{95}, the shape/position of the plasma, the up-down symmetry and the toroidal phase of the applied perturbation. The best ELM suppression is found for $3.5 < q_{95} < 4.0$ with an outer gap of 6-8 cm, dRsep = -2 cm, a lower triangularity of 0.7 and a relative toroidal phase of 0°. While the stochastic layer moves the edge electron pressure profile outward by less than 3 mm, the ion pressure gradient moves outward by several cm, as if the last closed flux surface has moved out radially. This shift in the edge gradient region is seen at multiple locations, including on the Thomson scattering system, the CER system, and on the magnetics. In the edge, the toroidal rotation drops within 50 ms and reverses, while in the core it decays by a factor of about 3 over 200-300 ms. Since Type-I ELMs are eliminated within one ELM period and changes in toroidal rotation takes ~50 ms (edge) to ~200 ms (core), these rotation changes appear to be unrelated to the suppression of the large ELMs.

Impurities expelled by Type-I ELMs prior to the formation of the stochastic layer are initially shielded by the change in edge magnetic topology induced by the I-coil. However, over a longer timescale (~1 s), there is an increase in the impurity sources from the outer midplane wall that contributes to an increase in the core Z_{eff} of about 10%, from 2.0 to ~2.2 due primarily to carbon. The particle flux to the divertor target is strongly suppressed within one ELM cycle by the I-coil perturbation. In addition, the heat flux to the divertor plate, as inferred from the surface temperature changes of the divertor tile near the strike point, becomes much less impulsive. The peak heat flux on the outer divertor target plates, averaged over many ELM periods, drops by about 50% and spreads out over a larger radial region when the I-coil is turned on, providing an additional benefit of handling the heat flux at the divertor target plates.

Vacuum field line integration modeling using the TRIP3D code [4] shows that the best ELM suppression occurs when a weak stochastic magnetic layer is formed across most of the pedestal with a narrow poloidal flux loss region (~3% in ψ_n) at the foot of the pedestal and a relatively large (~3-4% in ψ_n) island chain on the q=3 surface at the top of the pedestal (Fig. 2). The relative importance of the radial shifts of the pedestal pressure profiles with respect to each other compared to the enhanced effective radial transport in the stochastic layer for the ELM suppression are under investigation. Data obtained in 2004 will contribute significantly to: 1) understanding the physics mechanisms responsible for the suppression, 2) validating models of stochastic/island physics and 3) expanding the parameter space for getting good ELM suppression.

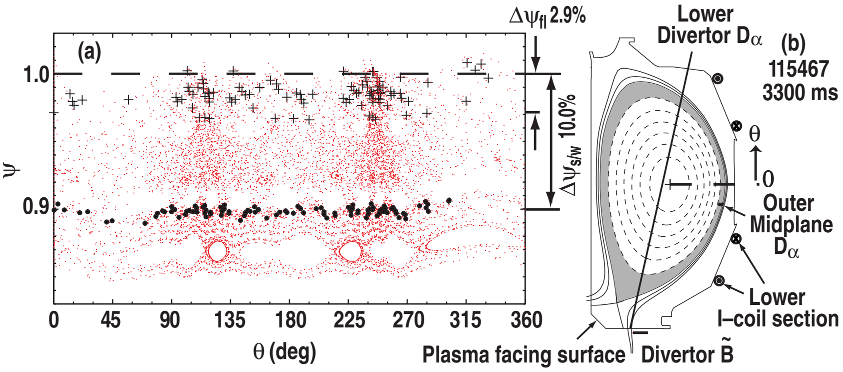

Fig. 2. (a) Edge magnetic topology calculated with TRIP3D for the ELM suppression discharge in Fig. 1. (b) Corresponding axisymmetric EFIT equilibrium, showing the TRIP3D computational domain in gray.

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