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GA–A26678

ELM CONTROL BY RESONANT MAGNETIC PERTURBATIONS: OVERVIEW OF RESEARCH BY THE ITPA PEDESTAL AND EDGE PHYSICS GROUP

by

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This is a preprint of a paper to be presented at the 23rd IAEA Fusion Energy Conference, October 11–16, 2010 in Daejon, Republic of Korea and to be published in Proceedings.

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Work supported in part by
the U.S. Department of Energy
under DE-AC52-07NA27344, DE-FC02-04ER54698
and DE-AC02-09CH11466

GENERAL ATOMICS ATOMICS PROJECT 30200
APRIL 2010

GENERAL ATOMICS

This paper presents a multi-tokamak overview of experimental results and planned hardware upgrades that will provide the essential physics understanding needed to project resonant magnetic perturbation (RMP) ELM control to ITER. Reduction of ELM size by at least a factor of 20 is critical to achieve acceptably low erosion of ITER material surfaces. The joint work reported here is part of the plan formulated by the PEP ITPA and ITER IO to provide the physics basis for the proposed use of internal RMP coils for ITER ELM control.

Modifications of ELM characteristics with RMPs have been achieved in JFT-2M [1], DIII-D [2], JET [3], MAST [4], and NSTX [5]. Figure 1 shows: (i) suppression of ELM energy losses using coils internal to the vacuum vessel in DIII-D, (ii) mitigation of ELM size with external coils in JET and with internal coils in both MAST and DIII-D, and (iii) pacing of ELMs with modulated RMP pulse amplitude in NSTX (also in DIII-D). Based on these results, significant upgrades of the RMP coil systems (Fig. 2) are underway on DIII-D, MAST and ASDEX-Upgrade (AUG) for their 2011 run campaigns.

Recent progress has been made in MAST and JET toward the ITER goal of 20x ELM size reduction, and reproducible sustained ELM suppression has been seen in DIII-D as shown in Fig. 1. Density pump-out, similar to that in DIII-D ELM suppression discharges, has been seen with *n*=1 or *n*=2 RMPs from external coils in JET H-mode plasmas and with *n*=3 RMPs from internal coils in MAST L-mode plasmas (Fig. 1) and reproduced by some simulations. In the MAST L-modes the amplitude of the pump-out increased with applied RMP amplitude in plasmas with or without edge rotation. ELM mitigation (reduction of energy losses and increase of frequency) has been obtained with *n*=1 or *n*=2 RMPs over a wide range of operating conditions in JET lower single null (LSN) H-mode plasmas but suppression of ELMs has not been achieved. Little effect on the ELMs has been seen with *n*=3 RMPs in MAST double null H-mode plasmas. Experiments continue in MAST plasmas with a new LSN shape similar to that in DIII-D.

Significant multi-institution work has been done to identify the criteria for ELM suppression from both experimental results and theory. One criterion, correlated with ELM suppression in DIII-D, is that the edge region with overlapping islands have adequate width [6]. This condition provided guidance for ITER on the required magnitude of the RMP field and the

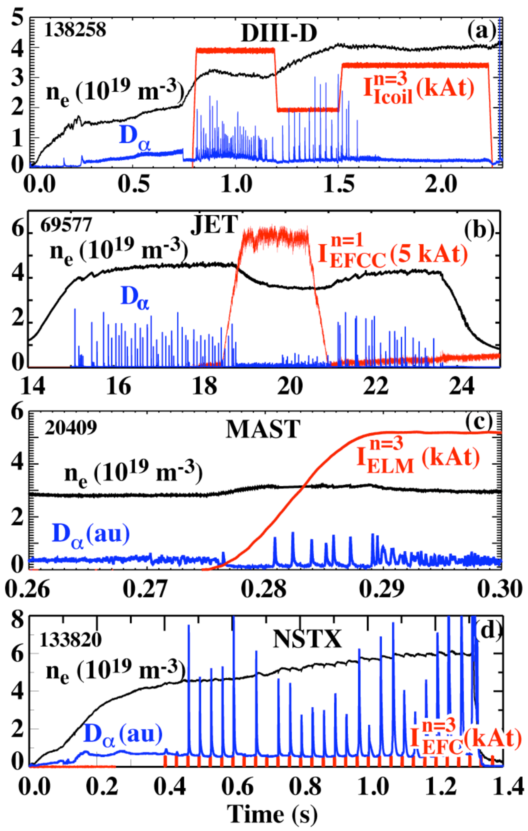

Fig. 1. ELM control data from (a) DIII-D, (b) JET, (c) MAST and (d) NSTX.

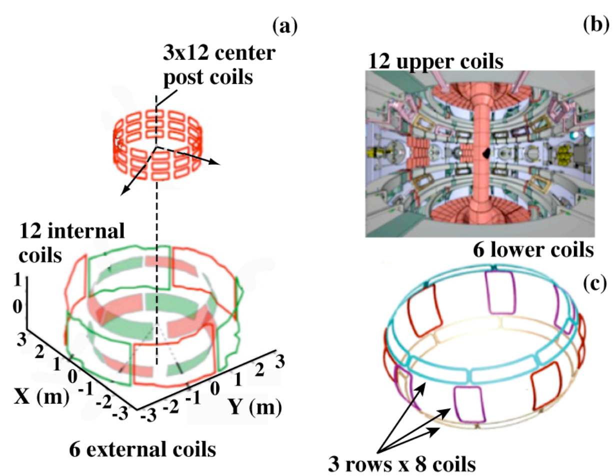

Fig. 2. Proposed systems of internal coils for 2011 RMP ELM Control experiments in (a) DIII-D, (b) MAST and (c) ASDEX-Upgrade.

resonance condition, but theory indicates that other physics considerations such as collisionality and details of the plasma response are important: recent experiments with internal coils in MAST and with external coils in JET have achieved this overlap condition, but have not achieved ELM suppression. Also, theory predictions of target plate heat and particle flux profiles during RMP in DIII-D and TEXTOR using the vacuum magnetic topology showed good agreement with some but not all measurements. Progress has been made on a theoretical prediction of RMP field penetration including the plasma response.

Work has continued to quantify the impact of RMP fields for ELM control on (a) pedestal pressure and core confinement, (b) divertor and main chamber wall loading, (c) ELMs during the current ramp and/or near the L-H power threshold, (d) core fueling by pellets and on (e) ELM pacing by RMP pulses. Recent DIII-D results have shown that ELM suppression can be achieved with no degradation of the line-averaged density or normalized β. Suppression of the first ELM after the L-H transition has been demonstrated and the effect of the RMP fields on the L-H power threshold has been investigated. The dependence of the resonant q_{95} window for ELM suppression on plasma current ramp vs toroidal field ramp and on collisionality have been examined and compared with peeling-ballooning stability theory. The effect of fueling pellets on the RMP ELM suppressed edge has been measured. RMP pulse modulation has been shown to pace ELMs in NSTX ELM-free discharges and to increase the frequency (decrease ELM size) in DIII-D H-mode plasmas.

The planned upgrades of the coil systems internal to the vacuum vessel on several devices (Fig. 2) will permit significantly greater variation of RMP mode spectrum to test physics models of RMP ELM control in 2011 experiments. A new set of three rows of internal coils on the centerpost of DIII-D, when used in combination with the present two rows of coils above and below the outer midplane, will ultimately allow variation of the RMP radial and poloidal localization plus the capability to separately rotate either n=3 or n=4 RMPs toroidally for tests of field penetration and heat flux spreading models. MAST will install additional internal coils above the outer midplane to increase their spectral flexibility. In this same time frame AUG will begin experiments with a new set of internal coils above and below the outer midplane. Within a year their plan is to upgrade to coils above, below and on the outer midplane in a configuration similar to the ITER design. JET and NSTX are currently engaged in studies of the feasibility of installing internal coils. These systems will greatly increase both the capability to test theoretical models of ELM control by RMP fields and the probability of achieving ELM suppression on multiple tokamaks worldwide.

This work was supported in part by the US Department of Energy under DE-AC52-07NA27344, DE-FC02-04ER54698, and DE-AC02-09CH11466.

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