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3D VACUUM MAGNETIC FIELD MODELING OF THE ITER ELM CONTROL COILS DURING STANDARD OPERATING SCENARIOS

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3D Vacuum Magnetic Field Modeling of the ITER ELM Control Coils During Standard Operating Scenarios ITR

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Vacuum calculations of the ITER Edge Localized Mode (ELM) coils indicate that island overlap, consistent with a DIII-D island overlap correlation criterion for ELM suppression, can be achieved in a range of ITER scenarios using either n=3 or n=4 perturbation fields. These studies aim to assess the adequacy of non-axisymmetric magnetic perturbation coils that are located between the blanket modules and the wall, in achieving ELM suppression. The coils must be capable of reducing fast energy transients, incident on the ITER divertors, due to large Type-I ELMs in 15 MA Q_{DT}=10 H-mode plasmas by at least a factor of 20 [1] to protect the tungsten and carbon-fiber-composite divertor target plates from premature surface degradation. In addition, these coils will be used to rotate the 3D perturbation fields from the upper, middle and lower rows toroidally with a maximum frequency of 5 Hz while holding the relative toroidal phase angle of the current distribution in each row of coils constant. This allows the heat flux that is channeled into the lobes of the magnetic footprints, such as those shown in Fig. 1, to be distributed more uniformly over a larger area of the target plates.

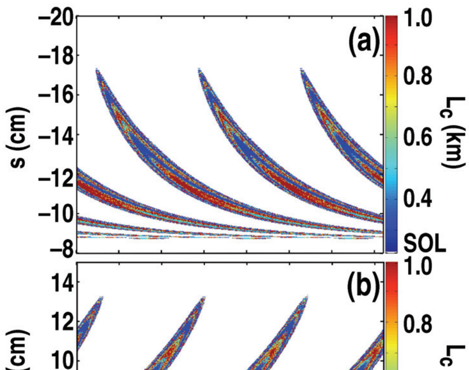

Fig. 1 Poloidal [s (cm)] vs toroidal [ϕ (deg)] distribution of magnetic footprints on the ITER divertor. The color bar shows the field line connection length (a) from the Low-Field Side (LFS) to the High-Field Side target and (b) from the HFS to LFS target.

In these studies, the coil spectrum is optimized by scanning the relative toroidal phase angle between the upper and lower rows of coils while holding the current distribution in the middle row fixed and making calculations of the edge vacuum island overlap width (VIOW) for each phase angle. Edge VIOW calculations produce island overlap widths equivalent to those obtained with calculations of the edge vacuum Chirikov island overlap width [2], to within the half width of the inner most overlapping island, when using the same toroidal mode numbers for the perturbation field in both calculations. The advantage of VIOW over Chirikov calculations is that there is no practical limit on the number of toroidal modes that can be used. Thus, VIOW calculations are more accurate due to the inclusion of high n perturbation fields that can often close gaps between lower n modes and significantly increase the width of overlapping vacuum islands across the edge of the plasma.

An automated code, based on a series of VIOW calculations, is used to analyze sinusoidal current distribution in each of the ITER ELM coils as a function of the toroidal phase angle between the three coil rows. Here, currents in each of the nine coils in an individual row are given an amplitude that approximates a spatially distributed cosine waveform and the toroidal phase of the distribution is scanned from 0° to 88° for n=4 or from 0° to 118° for n=3 distributions. As shown in Fig. 2, changes in the VIOW are represented by color variations ranging from blue (low) to red (high) when the phase angle of the lower coil, x-axis, and the upper coil, y-axis, are varied in 2° steps while holding the current in the middle row constant. This plot is used to identify current distributions that match a correlation criterion found in DIII-D during n=3 ELM suppression discharges. The DIII-D criterion is based on a statistical correlation between ELM suppression and the width of the edge region $\Delta W(\psi_N)$ having a vacuum Chirikov island overlap parameter σ_{CHIR} equal to or exceeding unity, where ψ_N is the normalized poloidal magnetic flux. Since a strong correlation has been found in DIII-D when $\Delta W(\psi_N) \geq 0.165$ in a subset of discharges [3], we use this criterion as an optimization parameter for the ELM coil current distributions in ITER as shown by the region enclosed by the black contour labeled "operating space" in Fig. 2. Previous 15 MA Q_{DT}=10 ITER H-mode ELM coil optimization studies using field line loss fractions and Chirikov island overlap widths [4] are found to be in good agreement with these VIOW results.

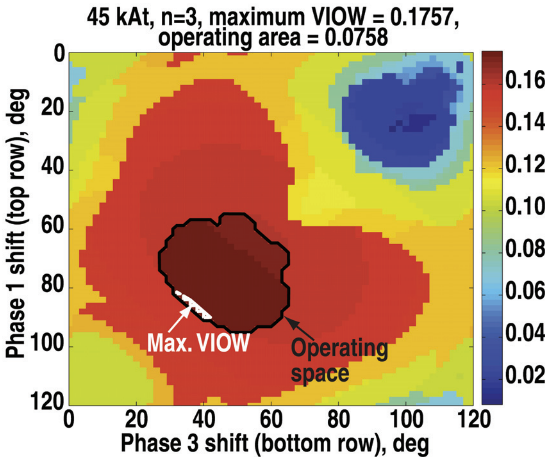

Fig. 2. The peak VIOW is located in the white region. The operating space meeting or exceeding the DIII-D criterion occupies 7.58% of the phase space at 45 kAt and expands to 84.4% at the maximum ELM coil current of 90 kAt.

VIOW optimization studies, using 5 kAt steps in the ELM coil currents between 5 kAt and 90 kAt and n=3 perturbation fields, have been completed for the following ITER operating scenarios: 15 MA Q_{DT}=10 H-modes with T_e^{ped}=3.5, 4.5, 5.5 and 6.5 keV, 15 MA quasi-double-null, 7.5 MA q_{95}=3.0, 9 MA Q_{DT}=5, 10 MA ramp-up, and 10 MA ramp-down. Results from these studies provide values for the minimum coil currents and phase settings required to satisfy the DIII-D correlation criterion for each of these operating scenarios. The minimum coil currents range from 50 kAt in the 15 MA Q_{DT}=10 H-mode scenario with T_e^{ped}= 3.5 keV to 25 kAt in the 9 MA Q_{DT}=5 operating scenario. It is also found that the available phase angle operating space satisfying the DIII-D criterion increases rapidly with the ELM coil current from the values found with the minimum currents. Similar VIOW optimization studies have also been done for several ITER operating scenarios using n=4 perturbation fields and for cases with random failures of up to 9 of the 27 coils. These results will be discussed along with plans to extend the analysis to include the plasma response to the perturbation field.

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