Asymmetric scrape-off layer currents during MHD and disruptions

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1. Introduction

In tokamak discharges, currents will transfer between the plasma edge and vessel structures by conduction through the scrape-off-layer (SOL). During disruptions, large asymmetric currents arise in the first wall and vacuum vessel that have the potential to damage the vessel or first wall, and understanding this behaviour is important for mitigating disruption loads. Disruptions have been observed to produce asymmetric vessel currents or plasma current asymmetries up to ~20% of the pre-disruption I_p [1]. These asymmetries can be measured through I_p measurements at different toroidal angles [1-3], by diagnostic tiles that measure currents into the vessel near regions of plasma-wall contact [4], and can also be inferred from vessel displacements [5]. In this paper, we report asymmetric SOL and vessel currents measured during MHD activity and disruptions in the HBT-EP tokamak [6], including measurements from newly-installed low-field-side (LFS) diagnostic tiles.

2. HBT-EP diagnostics for SOL currents

A rendering of SOL current (SOLC) diagnostics in HBT-EP is shown in Figure 1. Two poloidal arrays of poloidal field sensors are used to measure asymmetries in the plasma current ($I_p^{PAp} \oint \vec{B} \cdot \vec{dl}/\mu_0$, $\Delta I_p = I_p^{PA2p} - I_p^{PA1p}$) and its radial moment ($M_{IR} = \sum B_{\theta i}(R_i - R_{cent})dl_i/\mu_0$, $\Delta M_{IR} = M_{IR}^{PA2p} - M_{IR}^{PA1p}$). Four insulating toroidal breaks in the vessel allow for measurement of toroidal vessel currents when they are connected via diagnosed jumpers. Tiles attached to the LFS stabilizing wall measure currents into the wall with poloidal resolution in three toroidal locations. These tiles provide low resistance, low inductance
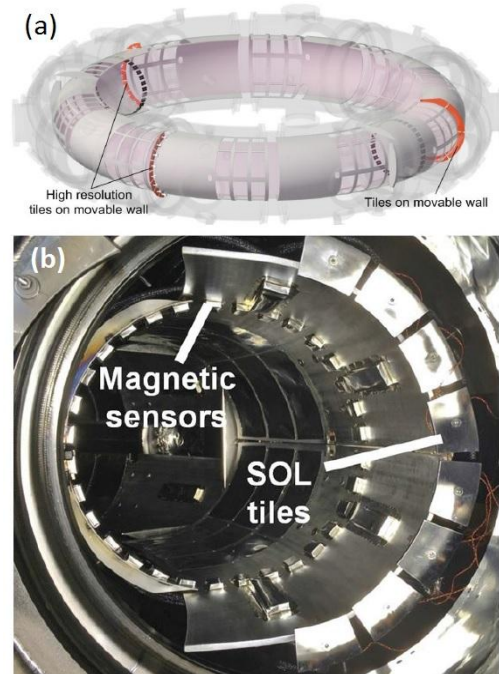

Figure 1: Magnetic sensors and SOLC tiles measure MHD activity with poloidal and toroidal resolution. Wall segments are radially adjustable between discharges without breaking vacuum.

current paths to ground. For the measurements presented here, only fluctuations in the detected current are shown. Undiagnosed blade limiters are also at the outboard midplane and top/bottom of the vessel in two toroidal locations for these discharges.

3. Observations during kink modes

Observations without the LFS tiles were previously detailed in Reference 3. Plasma parameters and SOLC measurements for example non-disruptive m/n=4/1 modes are shown in Figure 2. The discharge initiates with q_* near 4, producing a 4/1 kink mode that rotates and decays as q_* decreases. Oscillations indicative of SOLCs (Figure 2(g-m)) correlate with amplitude and phase of the kink modes. Currents are much weaker than disruption cases, here being below 0.5% of the equilibrium plasma current. The segmented plasma current Rogowski coils measure the largest asymmetry. As indicated in Figure 2(k-m), the vessel current is counter-I_p at the location nearest to the poloidal B_θ array that measures elevated plasma current. Entry and exit points for this current between the plasma and wall are confined to a 72° toroidal region of the vessel due to the insulating breaks. Examining Figure 2(k-l) around a mode phase of 110°, current from a grounded electrode at the plasma edge may cancel some of the toroidal vessel current relative to nearby mode phases.
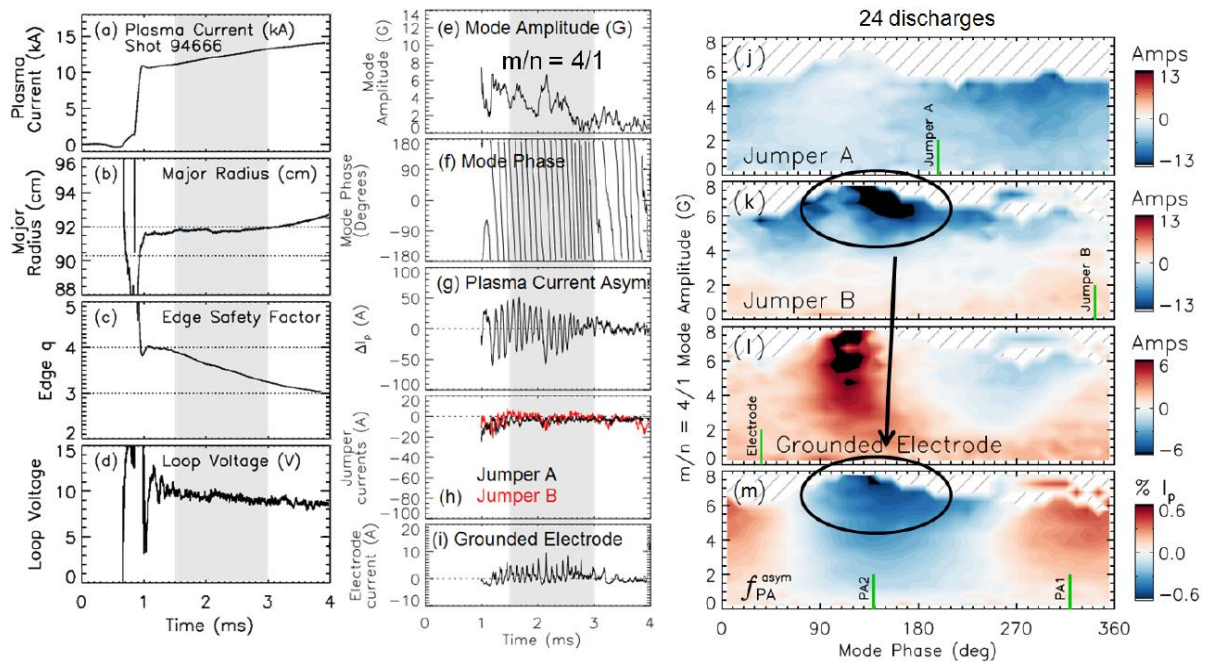

Figure 2: Plasma equilibrium parameters (a-d), mode amplitude and phase (e-f), and SOLC currents (g-m) for discharges with m/n=4/1 kink mode activity shortly after initiation of the discharge. The circled regions emphasize a case where counter-I_p vessel currents are co-located with an increase in the local measured plasma current. Adapted from Figures 2 and 4 of Reference 3.

Disruptions also produce clear phase and amplitude relations between rotating MHD modes and SOLCs, as shown in Figure 3, reproduced from Reference 3. Here, the plasma is high-field-side (HFS) limited and yields plasma current and vessel current asymmetries reaching 5% of the pre-disruption plasma current. The modes appear to be predominantly m/n=2/1 during these current quench cases.

When part of the wall is moved away from the plasma, as in Figure 4 with m/n=2/1 modes, there is a decrease in local toroidal vessel currents in response to MHD activity. However this decrease is not abrupt, and implies a thick SOL region extending over ~3cm ($\delta_{SOL}/a \approx 0.25$) that allows conduction of shared plasma-wall currents. This thick region may facilitate conduction of significant current when the closest structures would otherwise be limited by ion saturation current or poor conductivity. Note that this experiment was done with a ferromagnetic wall on one of the wall sections [7], which may extend the local SOL plasma closer to the wall. Moving the plasma for a fixed wall configuration also yields larger plasma current asymmetries for plasmas that are farther from being centred in the chamber.

Figures 2-4 and the results in Reference 3 do not contain poloidal information about where currents enter or exit the wall. After installation of the SOL tiles, shown in Figure 1,
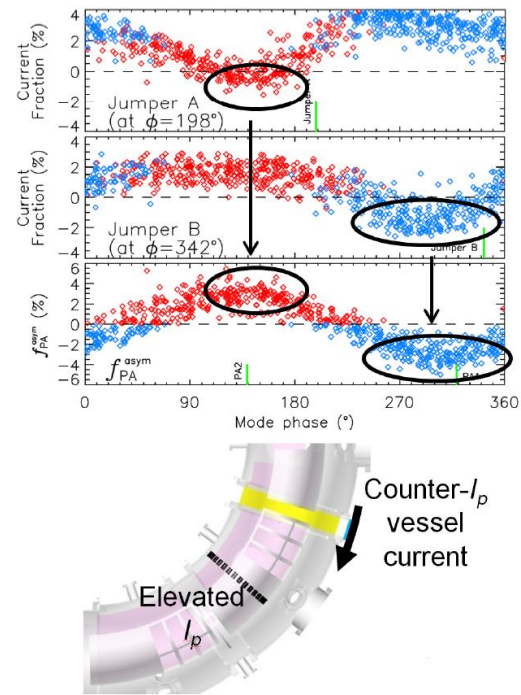
Figure 3: Toroidal vessel currents and I_p asymmetry versus mode phase during 10 disruptions. Circled regions emphasize where counter-I_p vessel currents are co-located with an increase in local measured plasma current. Plots are from Figure 12 of Reference 3.
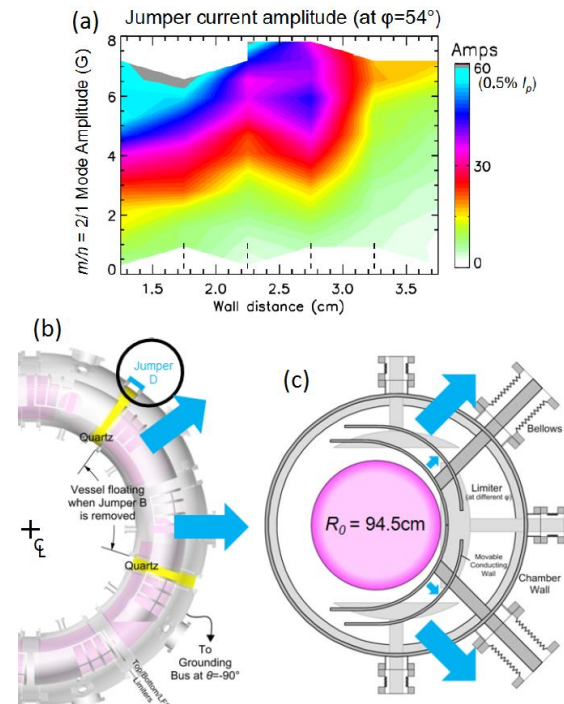
Figure 4: (a) Toroidal jumper currents versus m/n=2/1 mode amplitude and wall distance. Walls were retracted away from the plasma in two toroidal sections as diagrammed in (b-c). Data were taken with a ferromagnetic wall present, and before installing the LFS SOL tiles.

the poloidal structure of the SOLCs can be measured in three toroidal locations. These tiles diagnose SOLCs from kink modes during normal plasma operation, and inform the design of similar HFS components. Figure 5 shows measurements of a rotating 3/1 kink mode using poloidal field sensors and one set of SOLC tiles. The mode appears clear and coherent in both sensor sets. The other two poloidal arrays of SOLC tiles do not show the mode with a clear poloidal structure; this might be caused by radial misalignments of some tiles due to mounting on imperfect wall geometry. For this discharge the mode oscillations are mostly sinusoidal on both B_θ and SOLC sensor arrays, but other discharges yield much spikier bursts of current in the SOLC tiles even with sinusoidal modes in the magnetic sensors.
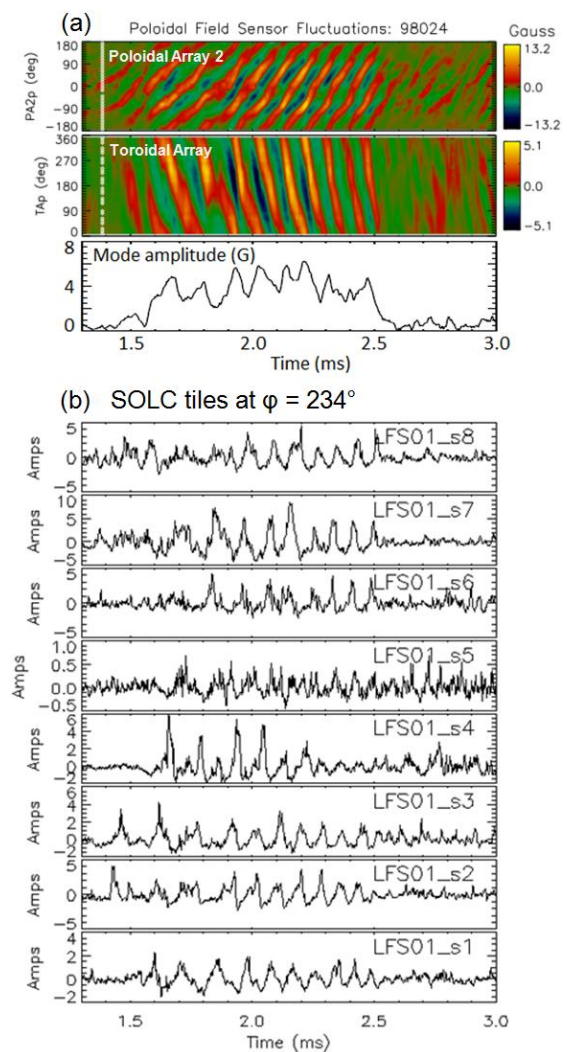
Disruptions are not well-diagnosed during the current quench with the present LFS SOLC tiles since the plasma always terminates toward the HFS. Passive and controllable HFS SOLC tiles with poloidal and toroidal resolution have been designed for HBT-EP, and will be installed in the near term. These will be used to characterize disruption SOLCs, and to control mode behaviour via electric fields and currents in the SOL.

Figure 5: (a) Magnetic fluctuations versus poloidal and toroidal angle, and (b) SOLC at one toroidal angle for an *m/n*=3/1 mode. Poloidal structure of the currents qualitatively matches the B_θ sensors. Quantitative mode geometry may not match in the sensor sets for a variety of reasons.

Acknowledgements

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