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HALO CURRENTS IN MAST AND RELEVANCE TO ITER

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Abstract Recent results from MAST suggest that during Vertical Displacement Events (VDEs), the plasma acts more as a voltage source than a current source when generating halo currents so that by altering the resistance of the current path it is possible to limit these currents. Although improved understanding of tokamak operation has greatly reduced the likelihood of uncontrolled plasma terminations it is impossible to eliminate such events completely. The halo currents associated with VDEs are of particular concern as these can be a significant fraction of the pre-termination plasma current and produce large forces on plasma facing components. Present extrapolations for likely halo currents in ITER[1] are based on empirical scalings from existing devices. MAST with its spherical geometry and comprehensive set of halo current detectors provides important additional information with which to test halo current models.

MAST[2,3] is equipped with a comprehensive set of halo current detectors, comprising 150 individual detectors. These are divided into four groups (see Fig.1); full Rogowski coils fitted around all the P2/P3 coil supports and at the top and bottom of the centre column (CC); arrays of partial Rogowski coils embedded in the P2 shield to measure radial and toroidal variations in halo currents; bands containing 12 B_{tor} pick-up coils at four heights on the centre column allowing toroidal and vertical variations in halo currents to be determined; and as part of a divertor biasing experiment[4] a number of the lower rib limiters have been soft-earthed through resistors with additional current and voltage diagnostics on the resistors.

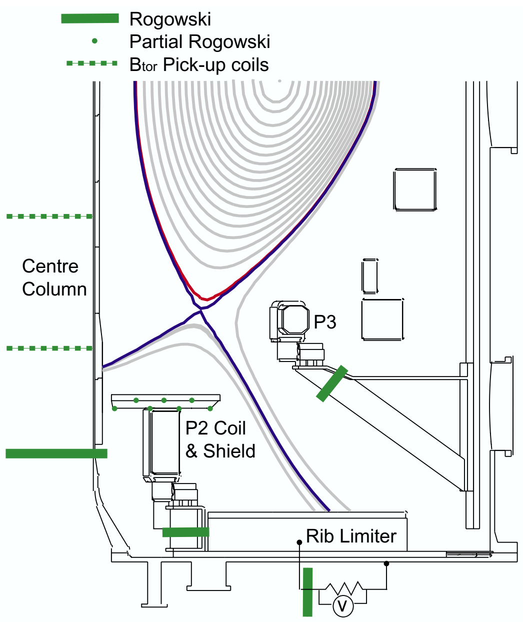

Figure.1 Schematic of divertor region of MAST vessel showing position of halo current detectors.

The magnitude of halo currents and the paths taken through the vessel structure are not only determined by where and how the plasma interacts with the vessel, but also by the plasma properties and the magnetic field structure. Halo current data for a typical discharge at a time during a downward VDE is shown in figure 2; the plasma current just prior to the VDE is approximately ~600kA.

The halo currents for the P2 coil supports, P3 supports and rib limiters have been summed

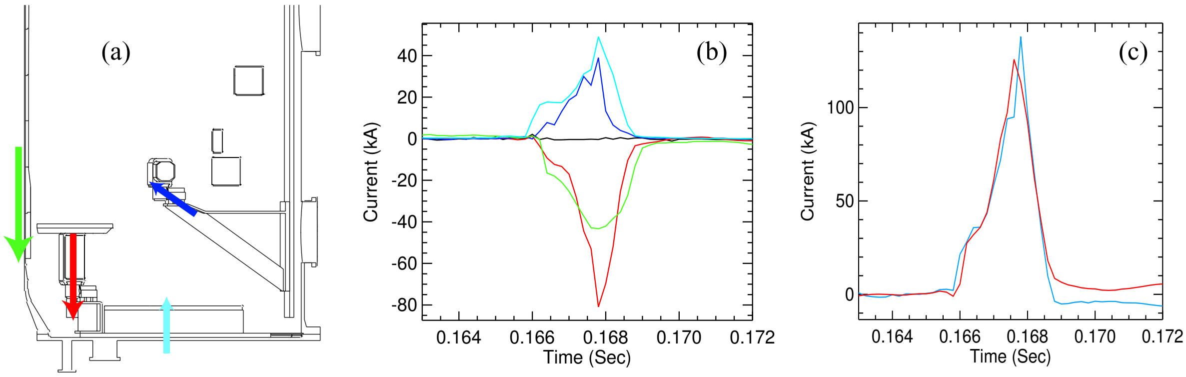

Figure 2: Halo current evolution for shot 3819, a downward VDE with plasma current just prior to the VDE of ~600kA.
(a-b) Halo current distribution in various components in the lower divertor region.
(c) Comparison of sum of positive and negative halo currents (‘sources’ and ‘sinks’).

to give the total currents flowing in each of the main components in the lower divertor region (fig.2a-b). Further comparing all the ‘source’ and ‘sinks’, the positive and negative flowing currents (fig.2c), shows that within experimental error all the currents paths are monitored. For the centre column, the majority (70-80%) of the halo current enters in the last 30cm section above the P2 shield in the region near the end of the solenoid where the stray radial field for the solenoid is strongest.

In MAST, VDEs are often triggered by an Internal Reconnection Event (IRE) which introduces a rapid change in vertical position which, at present, the vertical feedback system is unable to cope with. The typical time, start to finish, for a VDE is 2ms, though events as rapid as 0.4ms and as slow as 5ms have been observed. The VDE direction (up or down) is highly correlated with the TF current direction, with over 85% of VDEs being in the opposite direction to the current, but in all cases the majority of the halo current in the centre column is in the same direction as the TF current; this is important as it means that for components in this high field region the force is always compressive.

A database of halo currents has been created covering some 1000 discharges, with a wide range of plasma parameters. Figure 3 shows a summary of this data with halo current fraction plotted against plasma current, again the currents through the P2/P3 coil supports and rib limiters have been summed to give the total current in each region. The plasma current is measured before the VDE and any associated IRE that can significantly increase I_p just prior to disruption. The results are in broad agreement with those previously reported[5], with maximum halo current fractions in general similar to those observed in conventional tokamaks. Under normal ST operations, with I_p>350kA, halo current fractions above 25% have not been observed. Large halo current fractions are seen at low plasma currents, usually associated with large aspect ratio, and fractions up 85% have been produced in experiments where the plasma was driven highly unstable by ramping down the poloidal field currents. Even in this case for I_p>350kA the maximum halo current fraction seen so far is 33%. There is no significant difference in the data between up/down VDEs.

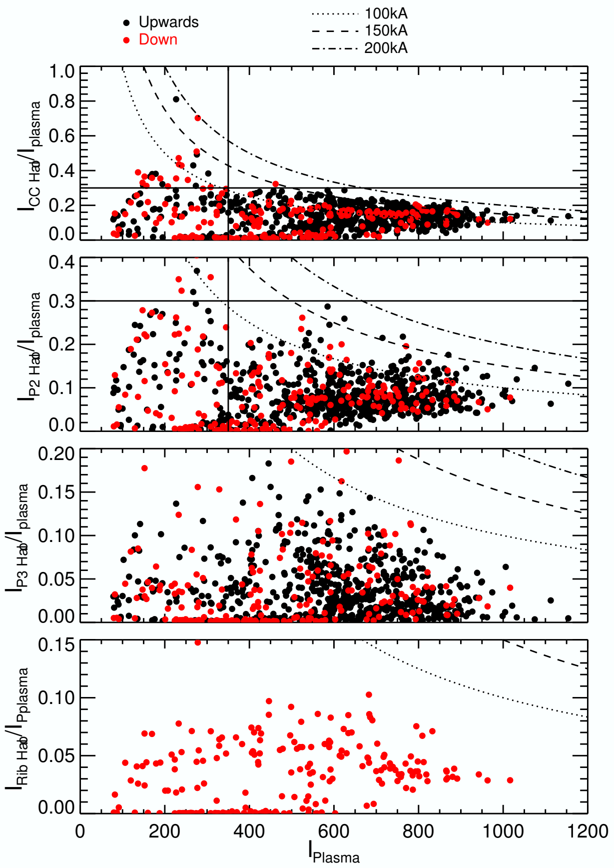

Figure 3: Peak halo current fractions for the four major components in the divertor region. Note halo current detectors are only measured on the rib limiters in the lower divertor region.

Toroidal asymmetries in the halo currents are as much an issue as the absolute magnitude, as these can produce large tilting/bending forces on components which in low aspect ratio devices are difficult to accommodate. Asymmetries are usually defined in terms of the Toroidal Peaking Factor (TPF), where TPF is defined as

$$1+\max[I_{halo}(i)\text{-Average}]/\text{Average}.$$

Figure 4 compares the MAST TPF data with that from the ITER database. The measurements follow the general trend seen in conventional devices with high peaking factors occurring at low halo currents, though the values lie well below the ITER upper design limit:-

$$TPF\times I_{halo}/I_{plasma}<0.75$$

Comparison of the peaking factor at four poloidal positions (centre column, P2/P3 supports and rib limiters) shows a general trend for the TPF to increase with poloidal position. The maximum TPF varies from 1.9 at the centre column to 3.9 at the P3 supports, and the TPF averaged over all shots varies between 1.14 and 1.92 for inboard to outboard measurements. This can be partly explained in terms of the increased differences in poloidal to toroidal path lengths at larger radius (i.e. toroidal path shorts out the asymmetry).

A series of experiments has been carried out to determine the effect of path resistance on halo currents. One of the lower rib limiters was soft-earthed through a resistor and the resistor value varied (0.1mΩ, 0.1Ω and 3.3kΩ). The voltage drop and current through the resistor were then measured. Increasing the resistance from 0.1mΩ to 0.1Ω decreased the halo current by a factor 6, while further increasing the resistance to 3kΩ reduced the halo current to below the level at which could be detected (<30A). The voltage across the resistor was measured using a 100kΩ, 1:100 resistor divider network. The results from the voltage measurements are more difficult to interpret than the current signals, the peak values are approximately the same (~60V), but the signal does not follow the current measurement closely and suggests some of the signal is pick-up. Taking this into account, the voltage seen by the rib limiter doesn't vary by more than a factor 3 for the three resistance values. This suggests that the plasma acts more as a voltage source than a constant current source and that it may be possible to protect vulnerable components by using soft-earths to limit halo currents.

The voltage measurements with R=3kΩ showed two unusual features; firstly the floating potential of the rib limiter could be seen throughout the discharge, and secondly large induced voltages, up to 300V, are detected during upward VDEs when the vessel is filled with a hot tenuous plasma. This indicates that there is an optimum value for R probably a few ohms which limits the current and voltage seen by components.

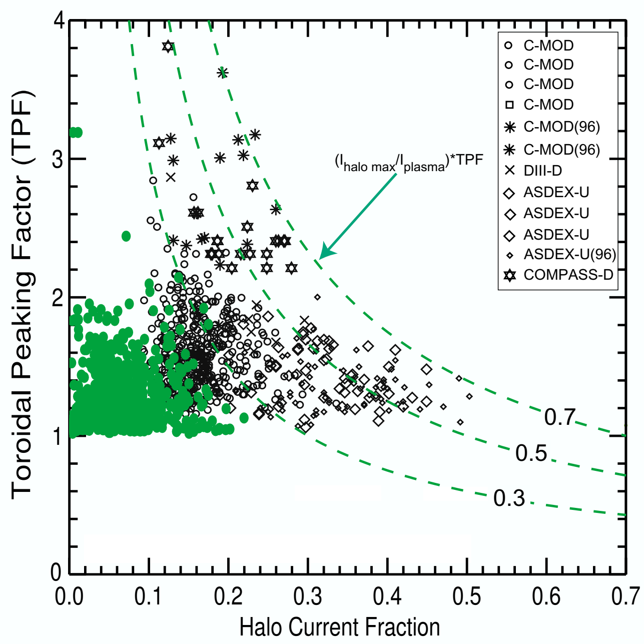

Figure 4: Comparison of MAST TPF data with the ITER database. MAST data all lies below $TPF \times I_{halo}/I_{plasma} < 0.3$, typical value for database 0.5

Conclusions: The large variations in measured halo current fractions between different tokamak experiments may be linked to small but significant variations in the resistance of available current paths. The effect of relatively low resistances ~0.1Ω in limiting maximum halo currents is important and could lead to engineered solutions for protecting in-vessel components using soft-earths. The trend for Toroidal Peaking Factor to increase with radial position is significant as it means that toppling/bending forces are less severe in the high field region than might be otherwise expected, and explains the lower average TPF seen in STs compared to conventional machines. Under normal ST operating conditions, with I_p>350kA halo current fractions above 25% have not yet been observed.

Acknowledgement:

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References:

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