ASCOT modeling of fast ion losses in DIII-D TBM experiments

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Introduction The testing of ferritic material in reactor conditions in ITER Test Blanket Modules (TBMs) magnifies the magnetic field ripple at three equatorial ports. Although the effect of periodic TF coil ripple has been fairly well studied both experimentally and theoretically, the effects of local ripples lacked experimental study until late 2009 when a scaled mock-up of an ITER TBM module was built and operated on DIII-D [1]. In the experiments, a significant temperature rise was measured on the wall tiles in front of the TBM module when the TBM error field was turned on. We have used the guiding center following code ASCOT [2] to simulate the fast Neutral Beam Injected (NBI) ion losses due to the TBM module and to determine whether the observed temperature rise could be explained by increased fast ion losses.

Background In this study the loss of NBI beam ions in two discharges, 140144 and 140156, of the TBM mock-up campaign are simulated. In these shots, the gap between the plasma and the first wall was changed from 5 cm to 8 cm. In both shots 5.8 MW of NBI power was injected with 4 co-beams in 140144 and 5 co-beams in 140156. The beam ionization profile was taken from TRANSP calculations.

The plasma background electron density and temperature are assumed to be functions of $\rho_{pol} = \sqrt{\frac{\psi_p - \psi_p^{axis}}{\psi_p^{sep} - \psi_p^{axis}}}$. Since for pure deuterium plasma $z_{eff} = 1$ the ion density is equal to electron density. Furthermore, since the heating power is relatively low, the ion and electron temperatures are also assumed to be equal. The plasma background profiles are shown in figure 1.

The magnetic field is a sum of the axisymmetric equilibrium field and the 3D vacuum TF coil and TBM fields, given in a discrete grid which covers all toroidal angles in 1° intervals. The TBM mock-up is located at the toroidal angle of 180° and the magnetic field is bent outwards at the TBM, creating strong local ripple. A poloidal map of the ripple strength $\delta = \frac{B_{max} - B_{min}}{B_{max} + B_{min}}$, where the extrema are taken over the toroidal dimension, is shown in figure 2 for the vacuum

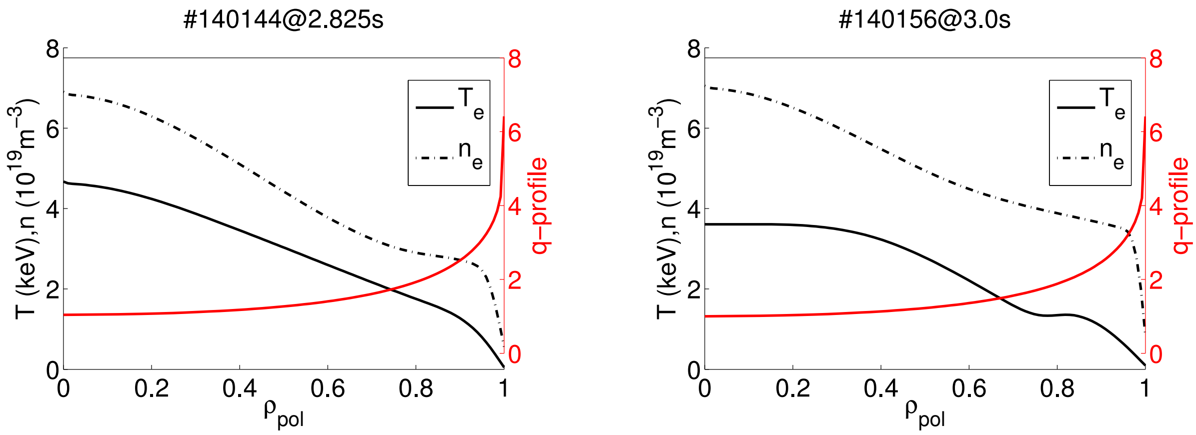

Figure 1: *Plasma temperature, density and q-profiles for shot 140144 (left) and shot 140156 (right). Ion temperature and density are assumed equal to electron temperature and density.*

field. The TBM field locally increases the ripple near the outer midplane, but it should be kept in mind that δ makes no difference between local and periodic perturbations. The maximum ripple strengths along the separatrix with the TBM field off and on are 0.36 % and 3.46 % in shot 140144 and 0.49 % and 4.79 % in shot 140156, respectively.

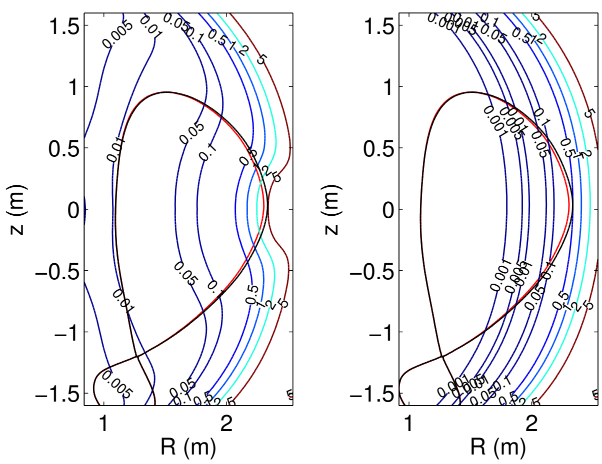

Figure 2: *Contours of the ripple strength in % with the TBM (left) and without the TBM (right). The LCFS is shown in red for shot 140144 and in black for shot 140156.*

Two different wall models, a simple 2D model and a more realistic 3D model can be used in ASCOT. The advantage of the 3D model in this study is that poloidal limiters can be taken into account. DIII-D has three limiters which protrude 3 cm from the vessel wall, which is a significant fraction of the plasma-wall gap. Since the Larmor radii of the injected ions are between 2 cm and 3 cm, the limiters are expected to have a significant role in shielding the first wall from the fast ions. Wall collisions with the 3D wall are calculated by retracing the final guiding center step with full orbit integration [3].

Simulation Results with 2D wall model

The wall power load from lost fast ions near the outer midplane in the case of an axisymmetric wall is shown on the left-hand side of figure 3. Three distinct loss regions can be observed: 1) A belt of discrete hot spots circles around the wall at the midplane. These are losses due to the

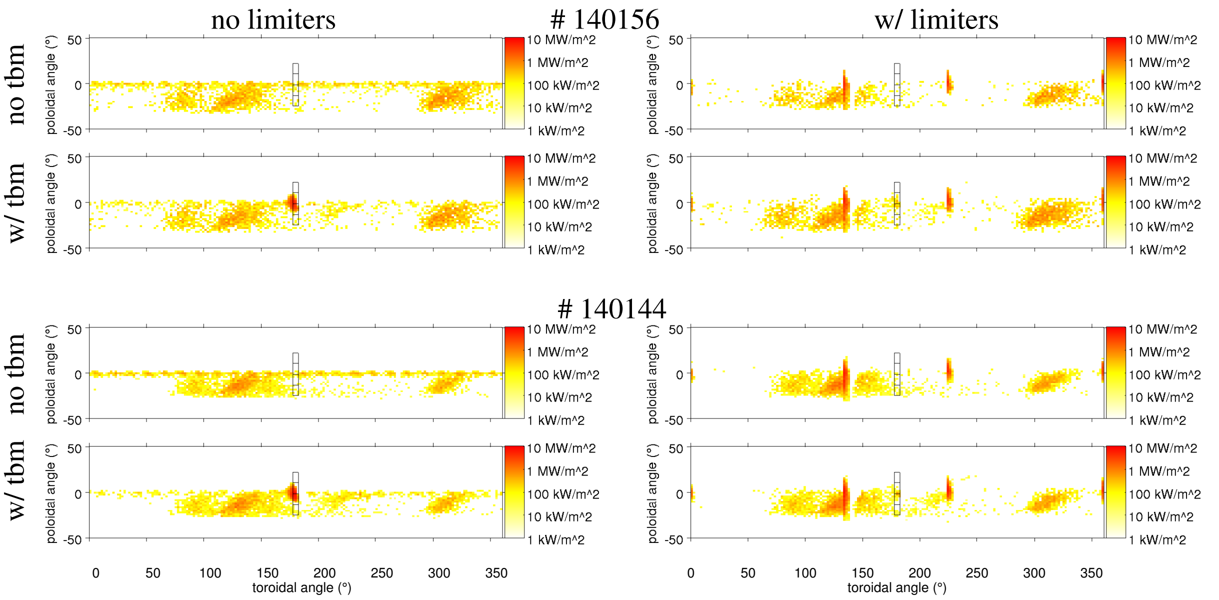

Figure 3: *Power density distributions on the wall on a logarithmic color scale. The tiles in front of the TBM module have been outlined in black. For both shots the calculation has been made 1) 2D wall without TBM (upper left), 2) 3D wall including limiters without TBM (upper right), 3) 2D wall with TBM (lower left) and 4) 3D wall including limiters with TBM (lower right)*

periodic TF coil ripple with one hot spot corresponding to each TF coil gap. 2) Three toroidally localized loss regions are located at approximately 80° 120° and 300°. These are created by direct-orbit losses from the beam ions that are ionized close to the separatrix. 3) A very localized hot spot is found at 180°, these losses are caused by the TBM perturbation, since they are only observed when the TBM is turned on.

Simulation Results with 3D wall model DIII-D has three limiters, two of which are located on the sides of the TBM mock-up module. To study the shielding of the TBM tiles by the limiters, a 3D wall model was constructed which contains three rectangular limiter blocks that protrude 3 cm from the first wall and have dimensions of approximately 20 cm $\times$ 80 cm. In our model, the limiters are located at 0°, 125° and 225° in toroidal angle.

The wall power load from lost fast ions in the case of a wall with limiters is presented on the righ-hand side of figure 3. Power deposition is observed on all three limiters, on the leading edge as well as the front, but none on the tailing edge. The direct orbit losses from ions close to the separatrix are not affected by the limiters, except where the limiter is lying on top of the prompt loss region at 125°. However, the vast majority of ripple lost ions is now deposited on the limiters and very little power is deposited on the TBM tiles. A summary of the power

Table 1: *Summary of fast ion power losses*

shot (140-)	144	144	144	144	156	156	156	156
tbm	on	off	on	off	on	off	on	off
wall	2D	2D	3D	3D	2D	2D	3D	3D
total input power (MW)	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
power loss fraction (%)	7.95	5.34	7.86	7.28	10.54	7.58	10.11	7.48
power on tbm tiles (kW)	23.98	1.02	3.00	0.99	25.93	1.45	3.03	0.48
power on limiter tiles (kW)	N/A	N/A	117.1	97.7	N/A	N/A	108.8	83.8

depositions found in the simulations is given in table 1.

Discussion and Future Work Accordint to these calculations, the TBM mock-up module in DIII-D was found to create a strong local ripple bending field lines outwards. We have found in simulations that the field line bending allows fast ions to escape confinement, which creates a hot spot on the wall tiles in front of the TBM. However, according to preliminary ASCOT simulations with a 3D wall, fast ions which would be lost to the TBM ripple are likely to be caught by the limiters that are several cm closer to the plasma than the TBM tiles. This result is similar to the one previously obtained for fusion alpha losses in ITER [4]. More work is still needed to benchmark these results to similar codes and to experimental data. We are already in the process of comparing the ASCOT results with the full-orbit code SPIRAL, which has also been used for modeling the same DIII-D shots.

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