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Initial results from phased ICRF operations on Alcator C-Mod

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Phased, high power antenna operation on Alcator C-Mod has been achieved with a compact 4-strap ICRF antenna [9], which can now routinely inject up to 3 MW (11 MW/m^2, 35 kV) with minimum density and impurity production, independent of phase. The heating efficiency and H-mode threshold are independent of the antenna phasing, and similar to that of the two 2-straps antennas installed on D and E-port. The C-Mod ICRF system, composed of this 4-strap launcher (J-port) and the two 2-strap antennas (D and E-port), has delivered up to 5MW for 600msec and offers unique opportunities to investigate technological and physics issues. We present here some results and future perspectives on novel impedance matching techniques, mode conversion current drive (MCCD) and fast particles effects.

LOAD TOLERANT MATCHING

Load tolerant networks [1] have been proposed as a possible technique to reduce the negative effects of ICRF loading variations, which limit high power operations in present systems. A prototype configuration, based on the conjugate tee approach [3, 7] (figure 1), has been evaluated on the Alcator C-Mod E-port antenna in plasma conditions. Modeling [7] predicted that the system could lead to significant asymmetries in the currents on the antenna straps. With the test configuration, this effect was observed experimentally (fig. 2) and resulted in a strong imbalance of currents in the poloidal direction. The heating efficiency and impurity production were compared to that of the unchanged D-antenna used as reference. Similar levels were measured, suggesting that ICRF antennas could operate in this configuration with this level of current asymmetry.

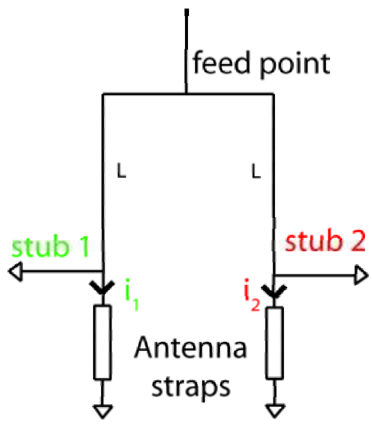

Figure 1: Conjugate tee configuration.

Strong strap-to-strap coupling introduces however another complication. Due to their compact design, the ICRF antennas in C-Mod have strongly coupled straps (-7dB for E-antenna) and strong coupling to the plasma. As power circulates between straps, the current imbalance results in asymmetric changes in the loading impedance at the antenna ports. According to modeling, this effect hinders load tolerant operation, which could not be achieved experimentally.

In a four-strap antenna array like J-port antenna, the configuration would be implemented on pairs of non-adjacents straps, which are less coupled (-20dB). Initial modeling of possible configurations showed that load tolerant behavior can still not be readily obtained, due to cross-coupling to the other strap pair. The compatibility of the system with other techniques to decouple the transmitters feeding the array is not straightforward. Toroidal phasing control, which is of interest for current drive and other physics tools, is lost due to current imbalance effects and therefore, flexible phased applications would not be guaranteed. Further investigation is needed to determine a suitable configuration for high power phased operations based on the conjugate tee approach.

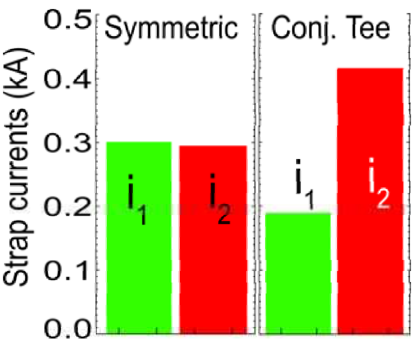

Figure 2: Measured current imbalance.

MODE CONVERSION CURRENT DRIVE

In multi-species plasma, the fast wave dispersion relation indicates possible mode conversion to ion Bernstein (IBW) or ion cyclotron waves (ICW). With an asymmetric $k_{||}$ spectrum from the antenna, the IBW and ICW can drive current locally through electron Landau damping [6].

In initial D(3He) MCCD experiments, where the power deposition was measured to be near the q=1 surface, co-current drive phasing decreased the sawtooth period to 5msec while counter-current drive phasing increased it to 15msec (fig. 4). Simulations using TORIC [2] indicated that about 10 kA was driven near the q=1 surface in this case. This local current is expected to change the mag-

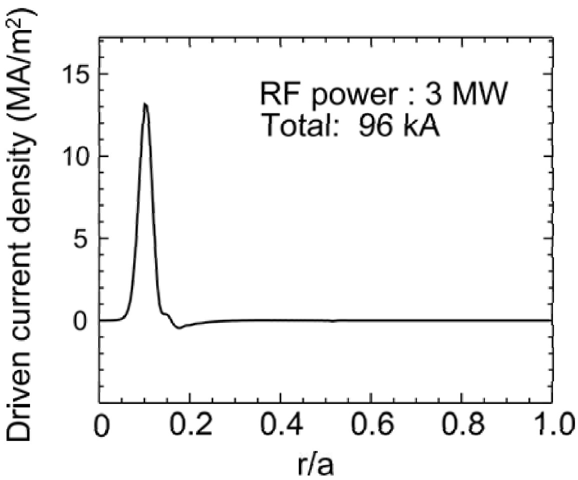

Figure 3: Driven current predicted by TORIC.

netic shear $\frac{dq}{dr}$ at the q=1 surface and therefore stabilize or destabilize the m=1 internal kink mode.

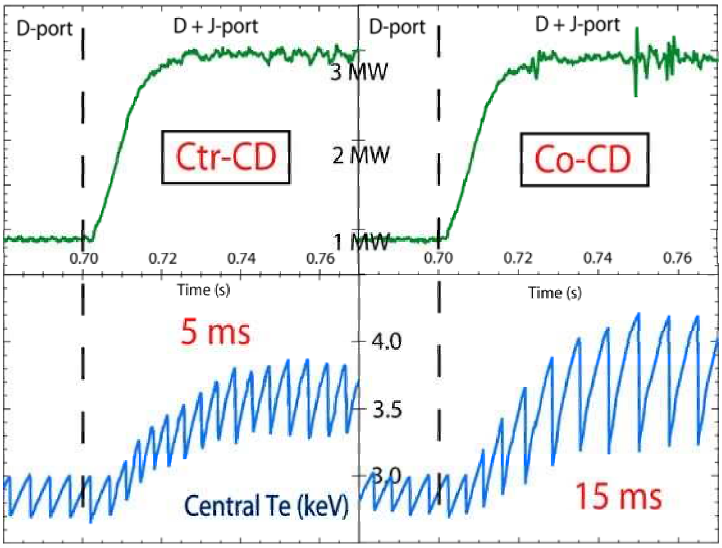

Figure 4: Sawtooth control through MCCD.

Using TORIC, scenarios with higher MCCD have been determined for Alcator C-Mod. In a deuterium plasma with 15% ^{3}He, 5% H, the ^{3}He-D hybrid layer for 50 MHz lies 1 cm away from the magnetic axis on the high field side. With 3 MW from J-port at this frequency, TORIC simulations predict that up to 90 kA could be driven (fig. 3) , with a current density locally similar to that of the ohmic profile. D and E-port at 80 MHz would provide H-minority heating on axis. This scenario will allow a detailed comparison between the observed driven current and theoretical modeling for different temperature, deposition location and plasma current.

In particular, the effect of the ICW on the current drive efficiency could be investigated experimentally. In toroidal geometry, the initial asymmetry in the $k_{\|}$-spectrum of the MC IBW is lost as the wave propagates and therefore the net driven current by the MC IBW is predicted to be small. In contrast, the ICW could drive significant levels of current in the plasma, as suggested by the TORIC modeling above. Due to $k_{\|}$-upshift effects, significant power is mode-converted to the ICW in C-Mod [5] for scenarios where the MC layer is slightly off-axis. However, the ICW current drive efficiency can be reduced significantly by magnetic trapping, as the wave propagates towards the low field side from the MC layer.

FAST PARTICLE EFFECTS

In recent campaigns, effects related to energetic ions produced by high power antenna operations have been observed in Alcator C-Mod. The first monster sawteeth in C-Mod were obtained with 5 MW input power: with on-axis deposition and J-port in heating phase, the sawtooth period could be lengthened to 80msec, compared to 5msec in the ohmic phase (fig. 5). This is compatible with fast particle sawtooth stabilization mechanisms [8]. Monster sawteeth were obtained for 800 kA and 1 MA plasma currents, but for 1 MA currents the sawtooth period could be not controlled efficiently. In contrast to results [4] from similar experiments in JET, the sawtooth control mechanism is also strongly affected by the phasing of the antenna. This dependence on the plasma current and antenna phasing for on-axis deposition will be further investigated.

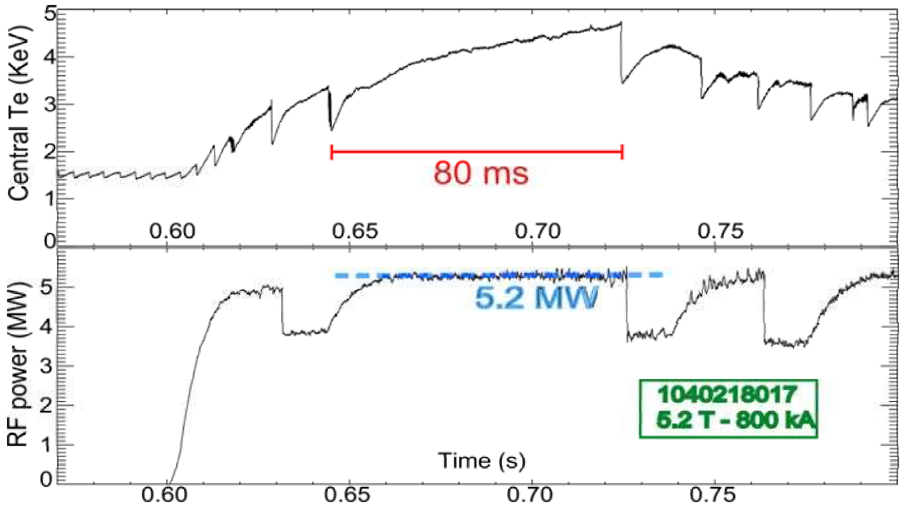

Figure 5: 80 ms monster sawtooth with on-axis deposition.

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