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Manipulating Energetic Ion Velocity Space to Control Instabilities and Improve Tokamak Performance[1]

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The first-ever demonstration of independent current (I) and voltage (V) control of high power neutral beams in tokamak plasma shots has successfully reduced the prevalence of instabilities and improved energetic ion confinement in experiments at the DIII-D tokamak. Energetic ions drive Alfvn eigenmode (AE) instabilities through a resonant energy exchange that can increase radial diffusion of the ions, thereby reducing beam heating and current drive efficiency. This resonance is incredibly sensitive to the ion velocity and orbit topology, which then allows changes in beam voltage (keeping the injected power constant through compensating changes in current) to remove nearly all instability drive. The implementation of temporal control of beam current and voltage allows for a reduction in the resonant energetic ion velocity space while maintaining the ability to inject maximum power. DIII-D low confinement (L-mode) plasmas demonstrate a nearly complete avoidance of AE activity in plasmas with 55 kV beam injection compared to the many AEs that are observed in plasmas featuring similar total beam power at 70 kV. Across the experimental range of beam settings, resulting increases in beam divergence have been inconsequential. High performance steady-state scenarios featuring equilibria that are conducive to dense arrays of Alfvn waves benefit the most from instability control mechanisms. One such scenario, the so-called high qmin scenario, demonstrates improved confinement and equilibrium evolution when the injected beam voltage begins at lower values (i.e., fewer resonances) and then increases as the plasma reaches its stationary period. These results suggest a future in which plasma confinement and performance is improved through continuous feedback control of auxiliary heating systems such that the energetic ion distribution is constantly adapted to produce an optimal plasma state.

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