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Impacts of 3D magnetic breaking on confinement and energetic particle transport in KSTAR

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It has been widely demonstrated that non-axisymmetric (3D) magnetic field induces toroidal rotation braking [1], which can be a powerful tool for control of the toroidal rotation profile [2, 3] and potentially the transport and confinement of the plasmas in tokamaks. In this presentation, we report an investigation of the impact of 3D magnetic braking on the confinement and fast ion transport in KSTAR. A set of magnetic braking discharges have been developed with injection of neutral beams (NBs) that supply strong toroidal torques to produce fast rotating H-mode plasmas. We utilized 3D magnetic field to drive toroidal rotation braking and electron cyclotron heating (ECH) to explore the lowest rotation level. In this experiment, toroidal rotation over a range of 120 - 300 km/s has been achieved at the core depending on the combination of NB, 3D field, and ECH, while the H-mode confinement was sustained during the flat-top. Confinement database have been established for fast and slow rotating H-mode plasmas in the range of plasma parameters of B_T = 1.6 - 1.8 T, I_P = 500 - 700 kA, and q_{95} = 3.7 - 5.4.

One interesting observation is the improved energy confinement phase achieved in some of developed discharges, which is triggered by 3D field driven toroidal rotation braking. We observe an increase of total stored energy by up to 15% although particle transport is increased due to the 3D magnetic field as shown in Figure 1. The improved confinement is confirmed by increase of ion and electron temperature and their gradients inside edge pedestal. ECEI measurement shows that in such discharges high frequency broadband turbulent fluctuations of ~200 kHz near the pedestal are largely mitigated and suppressed in the improved phase. FIDA measurement also indicates that fast ion confinement is improved during the same phase. Excitation of the toroidicity-induced Alfvén eigenmodes (TAEs) is observed in the one of the strongest braking discharges, which is destabilized by turning-on of the ECH under the 3D magnetic field. It is found that reform of the Alfvén continuum due to modification of the toroidal rotation and q profiles by the 3D magnetic field and ECH is responsible for the onset of the TAEs.

We will discuss the confinement characteristics of the 3D magnetic braking discharges in a wide range of parameter spaces, focused on the correlation between the confinement and toroidal rotation. It is found that total stored energy is roughly proportional to toroidal rotation velocity, while such trends different appear depending on the presence of 3D magnetic field. An interesting finding is that the stored energy is inversely proportional to the ratio of toroidal rotation velocity to thermal ion speed ($V_T/V_{i,th}$), in particular for magnetic braking phase, suggesting slow rotating plasmas may be more favorable to higher thermal energy confinement. The physics mechanism of modification of the confinement and fast ion transport associated with the magnetic braking will be discussed.

References

[1] J.D. Callen, Nucl. Fusion 51 (2011) 094026
[2] K. Kim et al., Nucl. Fusion 57 (2017) 036014
[3] K. Kim et al., Nucl. Fusion 57 (2017) 126035

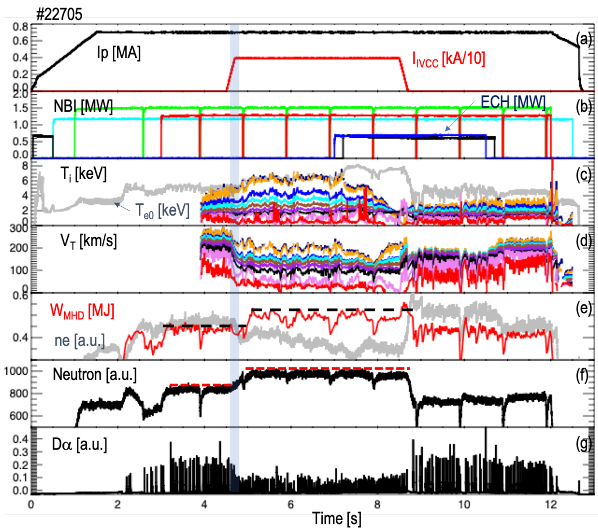

Figure. 1. Example of improved confinement discharge by magnetic braking (KSTAR #22705).

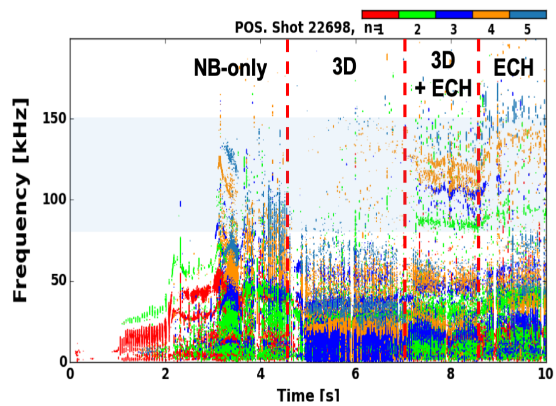

Figure. 2. Spectrogram of the magnetic braking discharge with the TAEs destabilized by ECH under 3D magnetic field (KSTAR #22698).