Contribution ID: **677** Type: **Regular Poster**

Improved energy confinement triggered by non-axisymmetric magnetic field driven rotation braking in KSTAR

Tuesday, May 11, 2021 6:25 PM (20 minutes)

Development of high performance operation regimes in the magnetic confinement fusion devices has been of great interest in the fusion community for decades as it is critical to accomplish efficient steady-state operations of fusion reactor. Since the first discovery of high confinement mode (H-mode) in tokamaks that claimed enhancement of energy confinement by more than a factor of 2 compared to low confinement mode (L-mode), a number of advances have been made to further expand the high performance confinement regimes. Examples of such efforts have been addressed as very high confinement mode (VH-mode), improved H-mode, internal transport barrier (ITB) discharges, enhanced pedestal H-mode (EP H-mode), Super H-mode, and so on. These regimes are typically identified by enhanced transport barrier either or both at the core and edge of plasmas, leading to higher energy confinement than the standard H-mode [1]. Toroidal rotation and shear flow have been greatly acknowledged for their roles in accessing the improved confinement regimes [2].
We report a new improved confinement discharge achieved in the relatively slow rotating plasmas in KSTAR experiment, triggered by non-axisymmetric (3D) magnetic field. A series of experiments for a purpose of control of toroidal plasma rotation has been performed utilizing 3D magnetic field and electron cyclotron heating (ECH). Plasma parameters are in the range of B_T=1.6T-1.8T, I_P=500kA-700kA, and q_{95}=3.7-5.4. Neutral beam heating of 4MW was injected using 3 beam sources, which supplies strong toroidal torque to generate fast rotating plasmas in the H-mode confinement. Then, the 3D magnetic field of $n = 1$ was applied to reduce the rotation and modify the rotation profile.
Time history of one of those discharges (#22705) is illustrated in Fig. 1. The 3D field coil current is turned on at 4.5s after H-mode transition and ramped up to 4kA/turn. The toroidal rotation is significantly reduced in the whole plasma volume by 3D magnetic field driven magnetic braking. Increases of ion temperature are observed along with the reduction of toroidal rotation. Particle transport is increased by the 3D field as shown in the density pump-out. Mitigation of ELMs was also observed. Surprisingly, total stored energy (real-time EFIT) is increased by up to 15% during the 3D field phase in spite of decreased density, which indicates improved energy confinement. Increase of neutron rate is consistently observed during the same period under the 3D field. It is notable that the toroidal flow is instantly damped by the 3D field in the whole volume (vertical shade), however build-up of the ion temperature and the stored energy is followed relatively slowly after the rotation reaches near-minimum level. This implies the rotation reduction by the 3D magnetic field triggers the improvement of the energy confinement.
The ECH of 2 x 0.6MW power launched at 6.5s under the 3D field further reduces the toroidal rotation and increases the particle transport while the improved energy confinement is maintained at a similar level. The ion temperature at the core drops after the ECH, and the electron temperature is raised to sustain the enhanced stored energy. This implies modification of the transport channel by the ECH. The stored energy returns to the earlier level without the 3D field soon after the 3D field coil is turned off even though the ECH is still on, which evidences the 3D field is responsible for the improved energy confinement. Finally, the reduced toroidal rotation is recovered to the similar level before the magnetic braking after the ECH is turned off. Such key transport features are similarly observed in a series of discharges produced with different I_P and 3D field coil current.
FIDA measurement indicates fast ion confinement is improved as well during the improved confinement phase under the 3D magnetic field, as presented in the time trace of FIDA intensity at the core in Fig. 2. The FIDA intensity is increased and sustained during the 3D and 3D+ECH phases. Such behaviors are consistent with the evolution of stored energy. However, the FIDA signal significantly drops after turning-off of the 3D field in spite of the same heating power, proposing the primary role of the 3D field for the improved fast ion confinement. Fast ion profiles will be analyzed using TRANSP and FIDASIM codes with realistic kinetic profiles, leading to a clearer understanding on the fast ion transport associated with the 3D magnetic field and ECH.
Profiles of toroidal rotation and plasma temperature are presented in Fig. 3 for a set of discharges of improved confinement. It is obvious that significant reduction of the toroidal rotation is strongly correlated to the build-up of ion and electron temperature (red & blue). The improved confinement can be identified by enhanced transport barrier around the edge pedestal, where pedestal heights are raised by up to 50%. Fluctuation measurement by ECEI finds high frequency turbulences of ˜ 200kHz near the pedestal are suppressed in the improved confinement phase, which is consistent with the kinetic profile measurement. Profile evolution in Fig. 3 also shows the ECH modifies transport channel to decrease and increase the ion and electron temperature, respectively. The height of the pedestal is lowered to the standard H-mode level in the ECH-only

phase after the 3D field is turned-off (green).

The newly achieved improved confinement mode can be characterized by modification of multiple transport channels by the 3D magnetic field, as represented by global rotation braking (momentum transport), limited density pump-out (particle transport), and enhanced stored energy (energy transport). Measurements consistently indicate that the 3D magnetic field and modified toroidal rotation play a crucial role in those processes. Interestingly, mitigations of ELMs were also achieved, which further benefits the improved confinement mode for future devices. We will carry out the gyrokinetic analysis [3] to reveal the origin of improved energy confinement associated with the toroidal rotation reduction and transport modification by the ECH.

References

[1] F. Wagner, Eur. Phys. J. H 43, 523 (2018)

[2] K.H. Burrell, Phys. Plasmas 4, 1499 (1997)

[3] J.M. Kwon et al, Comput. Phys. Commun. 177, 775 (2017)

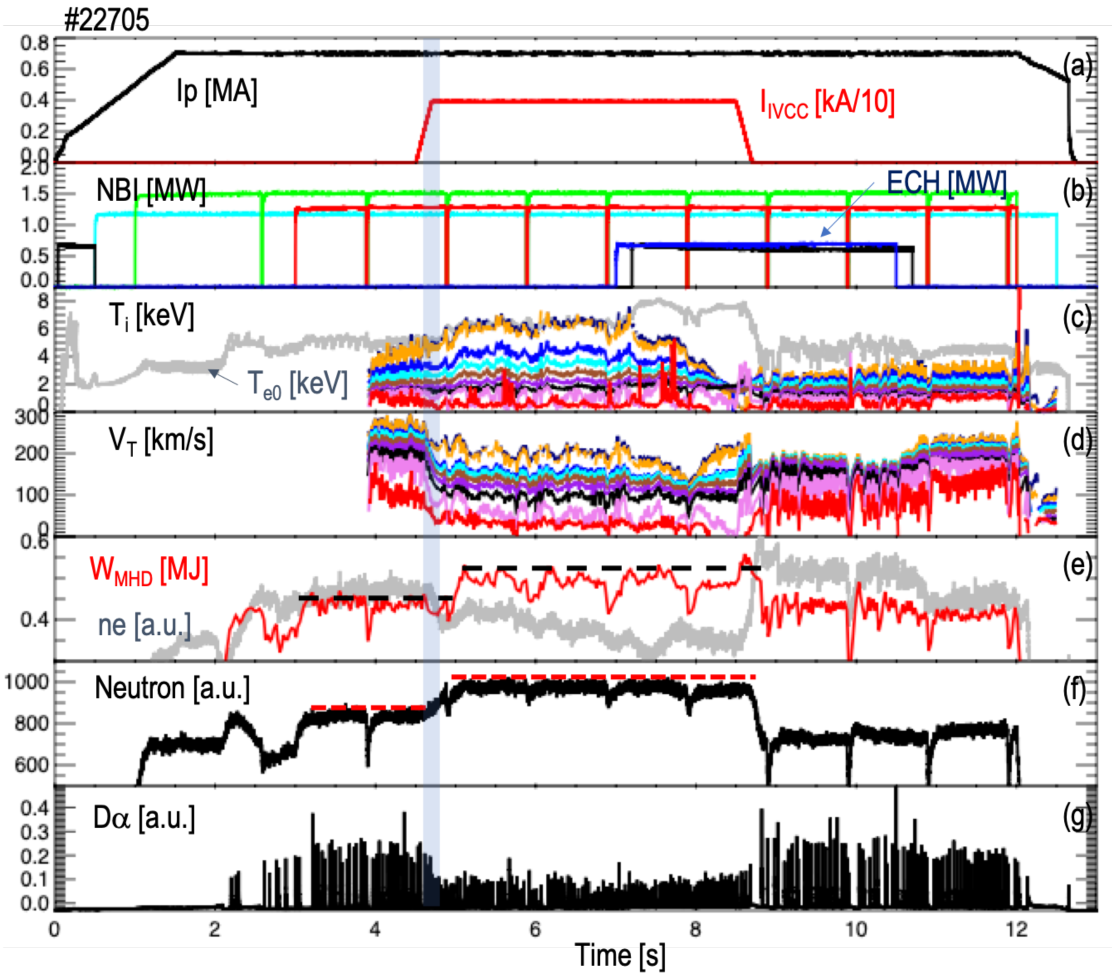

Figure 1: Time trace of the discharge of the improved confinement.

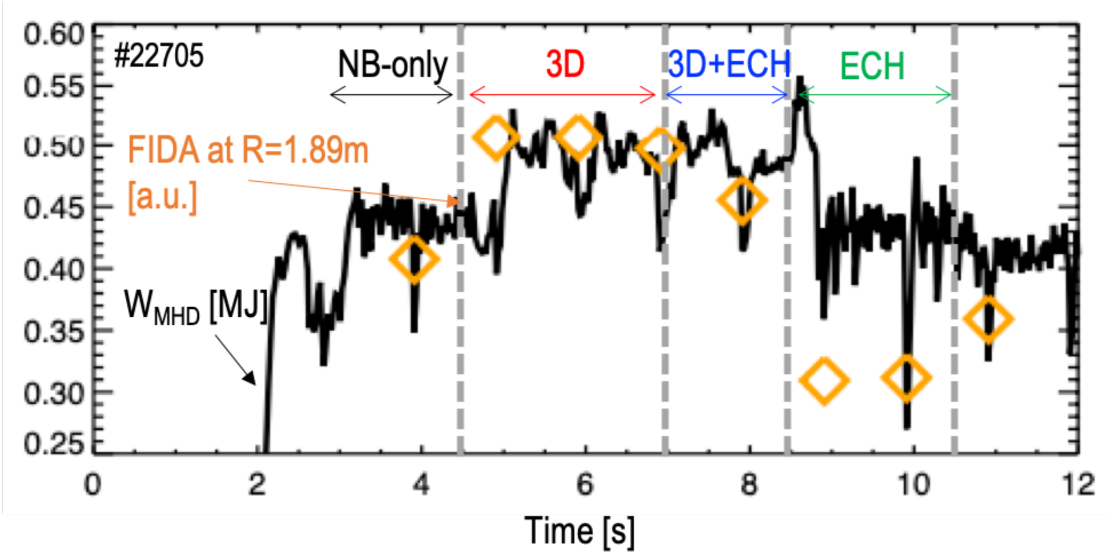

Figure 2: Core FIDA intensity overlaid on W_{MHD}.

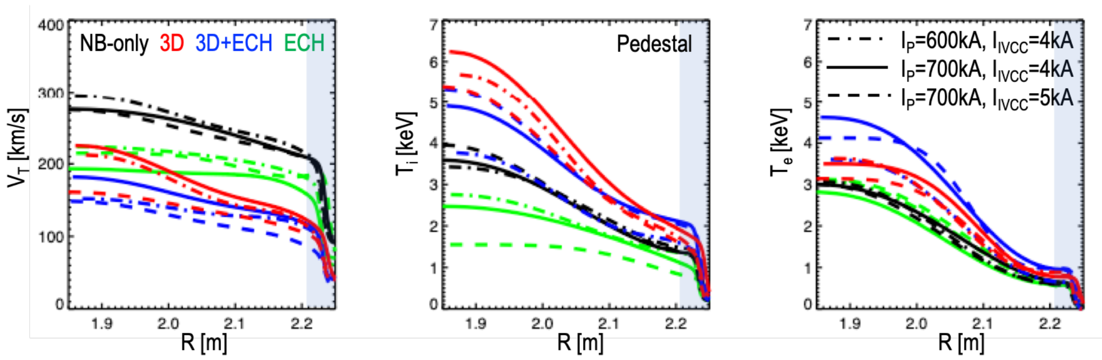

Figure 3: Comparison of toroidal rotation and ion and electron temperature profiles for 4 phases indicated in Fig. 2. Solid lines are for the presented shot #22705.

Affiliation

National Fusion Research Institute

Country or International Organization

Korea, Republic of

Primary author: Dr KIM, Kimin (National Fusion Research Institute)

Co-authors: Dr KIM, Hyun-Seok (National Fusion Research Institute); Dr KANG, Jisung (National Fusion Research Institute); Dr YOO, Jeongwon (National Fusion Research Institute); Dr CHOI, Minjun J. (National Fusion Research Institute); Dr KIM, Junghee (National Fusion Research Institute); KO, Won Ha (Korea, Republic of); Mr LEE, Myungwon (National Fusion Research Institute); Dr KWON, Jae-Min (National Fusion Research Institute)

Presenter: Dr KIM, Kimin (National Fusion Research Institute)

Session Classification: P2 Posters 2

Track Classification: Magnetic Fusion Experiments