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Recent experimental results on plasma current start-up and long pulse operation on QUEST

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The QUEST project aims at effective plasma current start-up and achievement of long pulse operation on spherical tokamak (ST) that has a potential to realize a cost-effective fusion power plant. ST has a difficulty to secure sufficient magnetic flux for plasma current start-up due to inherent narrower space in center region than conventional tokamaks. To resolve the issue, non-inductive plasma current start-up methods such as RF-induced current drive, helicity injection induced by plasma discharge along with the magnetic field, and toroidal plasma margining have been developed. In QUEST, electron cyclotron current drive (ECCD) [1-3] and coaxial helicity injection (CHI) [4] are investigated.

A good efficiency of ECCD could be obtained in the assist of energetic electrons (EEs) on QUEST [1], but the excess fraction may provide a damage on the vacuum vessel due to local heat load induced by the EEs. We developed methods to regulate the EE fraction using $k_{//}$ control of electron cyclotron wave (ECW) and negative toroidal electric field with center solenoid, here $k_{//}$ denotes wavevector parallel to the magnetic field. Relativistic effect and Doppler shift are well-working to modify the electron cyclotron resonance with finite $k_{//}$ and effective absorption of ECW power to the bulk electron can be expected in the case of lower $k_{//}$ than the case with higher $k_{//}$ [3]. Negative toroidal electric field could be applied from ohmic heating coils. The negative toroidal electric filed gives rise to reduction of the current drive efficiency, but avoidance of development of energetic electrons is more important to save the machine itself. Both methods give rise to increment of ECW power deposition to bulk electrons and electron temperature up to 1keV [5].

The CHI is one type of helicity injection and has a potential to play an important role in plasma current start-up. The injected helicity is produced by plasma discharge between electrodes along with the magnetic field. In NSTX, the vacuum vessel was used as the electrodes [6], but the method is not applicable for future power plants in the view of neutron damage of a ceramic insulator equipped with the vacuum vessel. Instead, a post-installed electrode has been developed on QUEST [7]. In the methods, the neutron-damaged ceramic can be replaced. But the configuration is likely to induce absorber arc that cause a significant loss of injected helicity. To avoid the absorber arcs, various magnetic configuration and gas injection has been tried in QUEST. Finally, the configuration and the gas puff system could be recognized as the best way. The CHI provided the highest toroidal current of 140kA and density of 6 x10^{19} m^{-3} and finally 90 kA confined in closed flux surface [4]. The values are sufficient for plasma current start-up, but higher electron temperature is preferable to use ohmic heating and ECCD. Further improvement should be promoted.

QUEST equips an all-metal plasma facing wall (PFW) that is required to prevent from excess tritium inventory. However, the PFWs was likely to enhance fuel recycling and break of particle balance frequently prevented from achievement of long pulse operation due to wall saturation (WS) that no fueling is required to maintain the plasma density. This indicates that the density is not controlled anymore during the WS and naturally increases the density without fueling. To overcome the difficulty, QUEST has equipped a hot wall that is temperature controllable PFW in the range of room temperature to 673 °K since 2018. The tendency that higher wall temperature causes faster WS was observed, but local wall temperature reduction provided longer pulse operation and consequently 6 h discharges could be obtained with the assist of the technique [8]. Furthermore, plasma duration of 40 min at 473 °K could be extended to more than 3 h.

References

[1] K.Hanada, *et al.*, *Plasma Science and Technology*, **13** (2011) 307-311 https://doi.org/10.1088/1009-0630/13/3/08

[2] H.Idei, *et al.*, *Nuclear Fusion*, **60** (2020) 016030 https://doi.org/10.1088/1741-4326/ab4c12

[3] T.Onchi, *et al.*, *Physics of Plasmas*, *28* (2021) 022505 https://doi.org/10.1063/5.0031357

[4] K.Kuroda, *et al.*, *Nuclear Fusion*, *64* (2024) 014002 https://doi.org/10.1088/1741-4326/ad0dd6

[5] T.Onchi, *et al.*, *Nuclear Fusion,* (2024) https://doi.org/10.1088/1741-4326/ad6914

[6] R. Raman, *et al. Phys. Rev. Lett.,* **97** (2006) 175002

[7] R.Raman, *et al. IEEE Transactions on Plasma Science*, **50** (2022), 4171-4176 https://doi.org/10.1109/TPS.2022.3193069

[8] M.Hasegawa, *et al. Plasma and Fusion Research*, **16** (2021) 1-8. https://doi.org/10.1585/pfr.16.24020