

Latest results on quiescent and post-disruption runaway electrons mitigation experiments at Frascati Tokamak Upgrade

Thursday 13 May 2021 12:10 (20 minutes)

Runaway electrons (RE) are one of the major concerns for ITER operations. In tokamak devices where fusion reactions take place at high rate and with large total current, the loss of plasma confinement can lead to runaway electrons formation (possibly up to 12 MA in ITER) via primary and secondary generation mechanisms [1,2]. The major issue with runaway electrons that form after the disruption is their high energy, mainly increased by the large electrical field at current quench (CQ), and the small pitch angle that could deposit unsustainable power on the plasma facing components causing deep melting in the tokamak structure. The main strategies on RE mitigation rely on increasing collisionality to avoid RE beam formation or to quickly dissipate its energy if already formed [1,8]. The latter action is unavoidably associated with undesirable fast-growing vertical displacement events, i.e. quick RE energy dissipation by heavy-Z material injection is linked with fast current decay leading to uncontrollable VDEs: it is a race among vertical displacement, energy dissipation and electromechanical loads that might not lead to ITER feasible solutions. Researchers are providing further techniques that might be used in combination with MGI/SPI such as a dedicated control strategy [3,4], 3D stochastic fields by resonant magnetic perturbation [7] and further instabilities [9]. Recent results obtained at DIII-D and further investigated at JET show that large RE currents, driven by the central solenoid after deuterium injection (SPI) to quickly reduce the drag, induce current-driven (low safety factor) kink instabilities with extremely fast RE beam loss and no sign of localized energy deposition, opening the path for an alternative RE mitigation strategy [3]. Continuing the studies of past years at FTU [4,5] we tested a number of alternative solutions for RE mitigation. In FTU large population of quiescent REs in steady state current ohmic discharges have been created and interaction with (multiple) deuterium pellets and Laser Blow Off (LBO) injection have been studied. In quiescent scenarios, it has been observed with a significative number of tests that D2 pellet on quiescent RE population might lead to REs fast growth up to the RE beam formation, if RE population or MHD activity is above a given threshold, meanwhile multiple pellets injection fairly close enough (1-20 ms) can produce quick REs total expulsion and or dissipation restoring a “safe” steady-state discharge with no REs as shown in Fig. 1 and Fig. 2. Different ablation rates of pellets with different size (1-2E20) depending on the REs quiescent population and inter-time pellet injection have been registered by fast H-alpha acquisition channels and the fast CO2 scanning interferometer. Such data can be important for pellet ablation models with REs that can be useful for ITER predictions. It is the worth to mention that pellet injections are as well the subject of studies at FTU for large MHD stabilization, possibly providing a solution to discharge recovery and RE preemptive dissipation at once. There have been also few cases in which pellets have been launched at CQ and, interestingly and somehow expected, the REs formed have lower energy. Indeed, one possible dissipation methodology would consist into providing a large number of electrons (deuterium injections) that could absorb at least part of the electrical field produced at the CQ preventing high level energy increase of RE seeding meanwhile flashing out all high-Z species at CQ would decrease the current drop and increasing then the RE beam controllability. It has also been observed, for the first time at FTU, density increase after D2 pellet injection as well as LBO ionization (and drag effects) on a post disruption RE beam with clear signs of increased background plasma temperature: fan-like instabilities seem to play an important role on such temperature increase. Modulated ECRH has been used in order to further increase background plasma density and temperature and a surprisingly synchronization with fan-like and MHD driven instabilities has been found. Data on RE energy evolution have been acquired with the new REIS [5,6] during RE quiescent flat-top as well as Ip ramp and post-disruption RE beam to provide data for RE energy model validation.

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To conclude, the FTU last experimental campaign provided data on D2 pellet effectiveness for preemptive RE mitigation technique, pellet ablation studies for ITER, as well as its effect on post-disruption RE beams and data for RE model validation.

Acknowledgement: This work has been carried out within the framework of the EUROfusion Consortium. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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Session Classification: P5 Posters 5

Track Classification: Magnetic Fusion Experiments