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Disruption mitigation in tokamak reactor via reducing the seed electrons of avalanche

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The disruption mitigation technology remains the key issue of safe and reliable device operation in future large tokamaks including ITER [1,2]. Several approaches have been proposed and experimentally tested in contemporary devices, which demonstrate opportunities of massive gas, pellets, dust and liquid gets injection in preventing the avalanche as the most dangerous mechanism of the runaway electrons. Physics of the avalanche [3] is determined by a very high electric field generated in tokamak at the final stage of the thermal quench that provides conversion of the plasma current from thermal electrons to runaways. It was shown that effective tool for the runaway avalanche mitigation is a fast growth of the plasma density above so called Rosenbluth density via techniques mentioned [4]. This density value is 100~1000 times higher than the plasma operation density. The mass of injected matter being in a kilogram range negatively affects technology systems sited the in-vessel and requires long-term recovery of the tokamak device in the created conditions. In this report, we analyze a novel approach aiming at an essential reduction of seeds causing the avalanche runaway electron generation after the thermal quench but does not use injection into the device vacuum vessel a large mass of gas, liquid or solid/dust matter.

The essence of the approach is to inject a projectile into the plasma from the material that is from the list of PFC materials (W, C, Be). The Fig.1 shows a schematic of the approach using the tungsten rod ~8 mm in diameter and 80 mm in length, that crosses the plasma volume with the velocity of 0.8 km/s perpendicular to the toroidal magnetic field. The projectile is injected just after the thermal quench (TQ) and crosses the plasma dimension in equatorial plane (4 m) at a time of ~5 ms. It collects all runaway electrons existing in plasma sequentially cleaning magnetic surfaces from runaways remained in the plasma after TQ (Fig.1). Such cleaning allows us to escape the runaway avalanche (or delay the time of the avalanche development) if the amount of primary runaways born during the plasma operation would be significantly reduced. The optimal scenario for this technology uses the following steps: control of the plasma stability and switching on the rail gun at the finish of the thermal quench; accelerating the projectile during 1.5 ms in the equatorial zone of device being aimed at collection of the seed electrons crossing the plasma during 5 ms; additional reconnection events stimulating seed runaway losses; capturing the injected projectile inside the collector sited inside the inner blanket zone of the tokamak-reactor.

Estimations of the tungsten projectile approach are performed for Basic Plasma Performance regime of ITER as in Ref. [5]. The stopping power due to interaction of runaways with the W projectile is evaluated by the relation *L*(mm) = 0.62[*E*(MeV)-0.106] from Ref. [6]. Runaway electrons within the 1~25 MeV energy range are terminated by the W projectile with the 8 mm dimension along the magnetic field. The 80 mm length and the 0.8 km/s speed of the projectile were chosen to provide existence of the projectile shadow at the magnetic surface needed to collect runaways during their ~800 toroidal transits within one-third part of the minor radius where the main source of seeds is expected.

Fig. 2 demonstrates temperature and density profiles prior and after the TQ together with the seed hot tail density *n*_{*seed*} ~ 5x10¹² m⁻³ that is evaluated assuming the 1 ms temperature decay time as in Ref. [7] and uniform profiles during TQ. The estimated *n*_{*seed*} value corresponds to the hot-tail seed current *I*_{*seed*} ~ 5 kA. Fig. 3 demonstrates evolution of the total and runaway currents during the current quench (CQ) stage of the disruption calculated for the strong electric field approach [2] with the Ohmic decay time of ~0.3 s corresponding to *T*_{*eCQ*} = 40 eV, *Z*_{*eff*} = 1.7 and the e-fold avalanche time of ~19 ms. One can see that for *I*_{*seed*} ~ 5 kA the large runaway current of *I*_{*run*} ~ 6 MA will replace the total current at ~0.5 s. Two orders the *I*_{*seed*} reduction results in delay of the runaway current rise so that the replacement will take place at ~1.0 s with *I*_{*run*} ~ 1.5 MA. This seems acceptable since the poloidal magnetic energy content is reduced by two orders of magnitude in comparison with that for the initial plasma current 15 MA.

Simulations of the projectile-plasma interaction show that the projectile surface temperature of ~ 1500 K will not exceed the tungsten sublimation threshold 5828 K, so that evaporation of the projectile can be neglected.

Estimates of the characteristics of a 0.6 m railgun made in accordance with [8] demonstrate the possibility of accelerating a projectile weighing 80 g to a speed of 800 m/s for 1.6 ms at a 1 MA railgun current in the magnetic field of a tokamak reactor ~5 T.

In conclusion, it should be noticed that the proposed approach to disruption mitigation via reduction of the seed runaway electron population immediately after TQ seems prospective. Collecting the seed runaways provided by the fast speed injected projectile from refractory materials (W or C) is capable to reduce the runaway current below of about MA even for 100-fold reduction of the seed current in conditions of a tokamak reactor. A stronger reduction of the seed current seems possible by optimization of the approach proposed.

Additional reconnection events initiated by this projectile [9] during penetration through the plasma volume are favorable for suppression of seed runaways.

References.
[1] Lehnen M., Maruyama S. 23 March 2018 ITER Technical Report 18-002.
[2] Breizman B.N et. al. 2019 Nucl. Fusion 59 08300.
[3] Sokolov Yu.A. 1979 JETP Lett. 29 244.
[4] Rosenbluth M.N., Putvinski S.V. 1997 Nuclear Fusion 37 1355.
[5] Lehnen M. et. al., 2015 J. Nucl. Mater. 463 39.
[6] Kiselev V.A. et. al., 2012 Instruments and Experimental Techniques 55 347.
[7] Smith H.M., Verwichte E. 2008 Phys. Plasmas 15 072502.
[8] Bobashev S.V. et. al., 2016 Technical Physics Letters 42 309.
[9] Kuteev et. al., 2006 JETP Letters 84 239.

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