Disruption mitigation in tokamak reactors

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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]. Several approaches have been proposed and experimentally tested in contemporary devices, which had demonstrated opportunities of massive gas, pellets, dust and liquid gets injection in preventing the most dangerous mechanism of runaway electrons avalanche. The avalanche physics is determined by a very high electric field generated in tokamak at the final stage of the thermal quench that provides a generation of runaways. It was shown that an effective tool for the runaway avalanche is a fast growth of the plasma density via techniques mentioned above up to so called Rosenbluth density [2]. This density growth must be provided during ≈ 10 ms time interval being 100 ~1000 times higher than the plasma operation density before the disruption. Such amount of the injected matter lying in range of kilograms, which negatively affects the in-vessel technology systems and requires long-term recovery of the device in the created conditions. This report presents a review of modern disruption mitigation techniques and a novel approach to the problem. The approach aims at struggle with seeds of runaways just after the thermal quench but does not use injection into the vacuum vessel a large amount of matter.

The target crossing the plasma volume is used to provide the seeds collecting during flight time in milliseconds time range. The material of the target may be of the PFC material list (W, C, Be). Cleaning the seed can delay development of the avalanche runaway electrons and significantly reduce their current. The optimal scenario for this technology includes the following steps: control of the plasma stability and switching on the rail gun (target’s accelerator) at the end of the thermal quench stage; accelerating and injecting the target into the plasma for collection of the seed electrons; capturing the injected target inside the collector sited inside the blanket zone of tokamak. Simulations of the target-plasma interaction for the Basic Plasma Performance regime of ITER [3] show that for injection from the low-field side in the equatorial ITER plane along the major radius direction the following effects are expected [4]. The W target will provide collecting the seed electrons with energies up to 25 MeV. The hot-tails seed current of about 5 kA causes the 6 MA runaway current after 0.5 s. Decrease of the seed source by the target in 100 times will reduce the runaway current to 1.5 MA. The target surface temperature will not exceed the tungsten sublimation threshold 5830 K. The railgun with 0.6 m length allows to accelerate the 80 g target up to 800 m/s velocity during 1.6 ms with the gun current of 1 MA in the ITER magnetic field of 5 T. Optimization of the target injection options, merits and demerits of the approach are discussed in the report together with the following R&D steps required.

References

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