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Plasma Control and Safe Discharge Termination during Disruption in Tokamaks

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Disruption instability and formation of the accelerated electron beams represent one of the main problems in design of the cost-effective fusion reactor. To minimize consequences of the disruptions in tokamaks, several methods for predicting disruption, controlling plasma discharge at the initial stage of the instability, and fast quenching (stopping) a plasma discharge are considered [1].

In experiments on the T 10 tokamak with all-metal (tungsten, lithium) in-vessel elements, it was shown that transition from quasi-stationary discharge to a fast phase of disruption can be associated with development of arc plasma discharges at the limiters [2]. New technique based on special movable electric and magnetic probes installed in the T-10 tokamak allows monitoring of the arc discharges and provide reliable trigger parameters for disruption stabilization systems and/or for safe discharge termination systems.

Possibility of restoration of the stable plasma discharge after start of disruption (during series of thermal quenches) at high density is studied in experiments on the T 10 tokamak using programmed operation of the Ohmic current supply system and gas puffing. For the first time, complete restoration of the plasma discharge with recovering of the pre-disruption plasma parameters (electron density and temperature) is obtained by sequentially controlled decrease in the plasma current with regulation of gas flows in the peripheral regions of the plasma and subsequent increase of the plasma current. Discharge recovery is accompanied by stabilization of burst of the magnetohydrodynamic (MHD) modes and prevention of the accelerated electron beams.

Injection of intensive gas flows and solid-state macroparticles is actively used to safely stop plasma discharge in modern tokamak experiments and is considered as one of the main systems for preventing development of the accelerated electron beams in the tokamak reactor ITER [1]. One of the main limitations in using these systems in large-scale tokamaks is weak penetration of the gas flows into central zones of the plasma discharge and long time response of the injected particles techniques. This reduces reliability of the disruption mitigation and leads to needs to testing additional methods for safe discharge termination. To minimize damaging consequences of disruptions, several "novel" methods of fast gas flow injection are tested in the T 10 tokamak, including injection of neutral particles from targets with biasing, injection of impurities sprayed with high-power microwave waves, and ultra-fast gas injection by initiation of rapid chemical combustion reactions (CCR). Experiments with CCR in T 10 showed that plasma shutdown starts from abrupt growth of the m°=°2 MHD mode provided effective penetration of the fast gas flows into the central zones of the plasma columns and quick stop the plasma discharge with plasma current decay rate of up to 35°-°40°MA/sec and control system response time of up to 0.1°msec.

Generation of the directed fast gas flows by initiation of chemical combustion reactions is tested at the Laboratory bench. Preliminary analysis has shown possibility of using fast-flowing chemical reactions initiating by substances with increased radiation resistance to the fast neutron fluxes, temperature stability, and high stability in vacuum conditions in the ITER-like tokamak reactor.
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[1] Lehnen M. et al, R&D for reliable disruption mitigation in ITER. Preprint: 2018 IAEA Fusion Energy Conf. (Gandhinagar, India, 22–27 October 2018) p.EX/P7-12.
[2] P. V. Savrukhin and E. A. Shestakov, Physics of Plasmas 26, 092505 (2019); https://doi.org/10.1063/1.5102112.

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Country or International Organization

Russia

Affiliation

NRC "Kurchatov Institute", Moscow, 123182, Russia

Authors: SAVRUKHIN, Petr (NRC Kurchatov Institute); Mr SHESTAKOV, Evgenij (NRC "Kurchatov Institute"); KHRAMENKOV, Alexander (NRC "Kurchatov Institute")

Presenter: SAVRUKHIN, Petr (NRC Kurchatov Institute)

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