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Advances in High Accuracy Physics-Based Tokamak Disruption Event Characterization and Forecasting Including Real-time Deployment

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Disruption prediction and avoidance is critical to maintain steady plasma operation and to avoid damage to device components in ITER and reactor-scale tokamaks. Physics-based disruption event characterization and forecasting (DECAF*) research determines the relation of events leading to disruption, and aims to provide event onset forecasts with high accuracy and sufficiently early warning to allow disruption avoidance [1]. The DECAF approach has been demonstrated to yield high accuracy disruption prediction and forecasting in both offline analysis and real-time application. A workflow has been established to reach next-steps: high accuracy under all plasma scenarios, and concurrent expansion of real-time deployment. The first real-time application of DECAF was made on the KSTAR superconducting tokamak including initial connection to control actuators. Dedicated plasma experiments focusing on disruptions caused by locking MHD instabilities were forecast with 100% accuracy. An MHD mode locking forecaster, using a torque balance model of the rotating mode, was implemented and utilized in real-time to produce these results. This forecaster was also used several times in these experiments to cue controlled plasma shutdown, trigger disruption mitigation using the KSTAR massive gas injection (MGI) system, and actuate electron cyclotron current drive and n = 1 rotating 3D fields for future disruption avoidance. New hardware and software for real-time (r/t) diagnostic acquisition and DECAF analysis continue to be installed and tested on KSTAR including high bandwidth (500 kHz) electron temperature, Te, profiles from electron cyclotron emission (ECE), and toroidal velocity profiles from a new r/t CES diagnostic with data taken in the 2023-24 run campaign. Several new r/t DECAF modules are being deployed on KSTAR, and first steps are being taken toward DECAF deployment on ITER. Research advances supporting these efforts include high bandwidth Te profile measurements being used to reconstruct 'crash profiles' to computationally identify sawteeth, ELMs, and other MHD as NTM triggers and as direct disruption precursors. Different DECAF disruption event chains are observed based on the plasma state at the time of the trigger event. Offline analysis has access to the full databases of many international tokamaks to best understand, validate, and extrapolate models. Fully automated analysis shows for datasets spanning entire run campaigns very high true positive rates, in some cases over 99%. A multi-device study conducted for plasma vertical instability used the DECAF workflow to produce real-time capable modelling with prediction accuracy of 99% -100%. An initial halo current model has been implemented to supplement criteria to determine the need of disruption mitigation.*

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References

[1] S.A. Sabbagh, et al., Phys. Plasmas 30, 032506 (2023); https://doi.org/10.1063/5.0133825

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