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Assessment of vertical controllability using DECAF, and predictive capability of a vertical stability metric for tokamak plasmas

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Vertical displacement events (VDEs) in tokamaks involve large displacements of the plasma magnetic axis from the vessel midplane, often leading to disruptions. These events are of particular concern for their potential to cause damage to plasma-facing components, as well as large forces on the vessel due to halo currents generated during the disruption that run through the plasma and vessel [1]. Detection and control of these events and mitigation or avoidance of a potential disruption is crucial. We present the results of an operational space analysis for defining regimes of vertical position controllability, compared across the MAST-Upgrade, KSTAR, and NSTX tokamaks using the DECAF*approach [2, 3]. Identification of the vertically-controllable regime based on device data is demonstrated to improve the accuracy of automated vertical displacement event detection to more than 99% for each of the devices studied. These findings can inform the setting of warning levels in real-time plasma control and disruption mitigation systems. Further, we present the results of a vertical instability warning metric that employs a linear model approximation of the current density profile of the plasma. This approach increases VDE early warning times on average by more than a factor of three and achieves 63% accuracy evaluated on full run campaigns of MAST-U data, and 87% accuracy evaluated on all shots from these campaigns without suspected internal reconnection events before the VDE. These results make this a promising method for forecasting vertical displacement events and triggering disruption avoidance procedures in a plasma control system, and motivate further refinement of the current model for robustness to internal reconnection events. This research was supported by the U.S. Department of Energy under grants DE-SC0020415, DE-SC0021311, and DE-SC0018623.*U.S. and international patents pending.

[1] V. Zamkovska, et al., "Implementation of a cross-device model for halo current in the DECAF code as a criterion for the determination of disruption mitigation action", this conference
[2] S.A. Sabbagh, et al., Phys. Plasmas 30, 032506 (2023). https://doi.org/10.1063/5.0133825
[3] S.A. Sabbagh, et al., "Advances in High-Accuracy Physics-Based Tokamak Disruption Event Characterization and Forecasting Including Real-time Deployment", this conference

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