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Disruption Prediction for Different Operational Phase Based on Disruption Budget Consumption on J-TEXT

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Plasma disruptions are catastrophic events in the operation of tokamak devices, causing abrupt termination of discharges: thermal quenches (TQ), and current quenches (CQ). The thermal loads, electromagnetic loads, and runaway currents from the disruption can severely damage the device structure. For ITER's successful operation and achievement of its operational goals, precise disruption budget management is essential. The longevity of the device during different phases of ITER operations is determined by the thermal loads during TQ, electromagnetic loads during CQ, and the damage of runaway electrons (RE).

To quantify the impact of the disruption damage, we conduct a disruption budget consumption (DBC) [1] analysis for each discharge under different plasma current and thermal energy conditions on J-TEXT. DBC represents the potential "cost" in terms of magnetic and thermal energy for each discharge scenario if a plasma disruption occurs. This impact is cumulative. Accurate DBC assessment is fundamental to achieving low disruption rates and high success rates of mitigation. To achieve the target disruption rate, avoidance and prediction strategies must be formulated. The capability to achieve the target mitigation rate depends on developing reliable disruption prediction techniques and effective mitigation methods. Accurate disruption prediction can use DBC to develop strategies for model building, leveraging discharge experiment data under different operational conditions. Quantifying DBC requires sufficient physical basis to establish a credible and feasible disruption prediction research strategy.

Considering the primary damage of disruptions, DBC quantification involves selecting parameters related to plasma thermal and magnetic energy. The thermal loads' damage to the device is mainly from the melting of the first wall. Literature on the impact of thermal energy on first wall melting highlights pre-TQ thermal energy, plasma current, and radiation power as significant parameters. The electromagnetic loads' damage manifests during the CQ phase due to halo currents from vertical displacement events and rapid current drops inducing eddy currents on the first wall. Halo currents primarily affect the vacuum vessel's electromagnetic stress, while eddy currents are the main factors influencing the poloidal force on blanket modules [2]. However, since there are no vertical displacement events on J-TEXT, the main damage comes from eddy currents. Thus, CQ rate and CQ duration are crucial parameters for magnetic energy hazards on the device. Runaway currents on J-TEXT mainly result from the thermal tail mechanism, with toroidal field parameters also being significant.

For these critical parameters, we propose a quantified DBC, assigning a "cost" to each discharge in each operational range. This "cost" is based on plasma current, toroidal field, radiation power, CQ rate, and CQ duration at disruption occurrence. In constructing the training set, we cover discharge data across different operational ranges without damaging the device, allowing machine learning models to learn richer disruption mechanisms. Guided by disruption budget information, we optimize the training set to prevent severe device damage while covering various operational scenarios, thus improving model prediction performance. In this way, it can be figured out how to conduct experiment plan in different operation ranges for better disruption protection. For future device operations, DBC can provide more discharge guidance, assigning a "cost" to each discharge, protecting the device while acquiring operational data. When the cumulative DBC reaches the device's tolerance threshold, maintenance and equipment replacement can be performed. This can provide a new disruption predictor assessment metric which is called "cost curve".

References

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