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Disruption Thermal Load Mitigation with JET SPI

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Disruption mitigation remains a unresolved critical issue for ITER. Over 90% of the massive stored energies in ITER must be radiated for a mitigated disruption [1]. The most promising present strategy is to inject a large amount of material into the plasma using a shattered pellet injector (SPI). This study presents an exploration of SPI parameters on mitigation performance and the mitigation efficacy measured using the recently installed SPI on JET.

The JET SPI system incorporates three barrels of different size that can be used in parallel. Scans were conducted varying neon/deuterium mixtures, pellet size and velocity, arrival interval between multiple pellets and target plasma conditions[2]. Two scenarios with an ITER relevant q_{95} were selected; 2.5MA/2.5T and ~1.0MA/1.15T. Both had nominal auxiliary heating of 15MW which was scanned in dedicated experiments. The 2.5MA scenario was selected due to its high total thermal energy and the 1.0MA scenario provided a relatively high thermal energy fraction (f_{th}) due to its lower magnetic energy content. The chosen figures of merit for SPI performance were radiated energy fraction (f_{rad}) and the current quench duration (τ_{CQ}). Although f_{rad} produces a non-dimensional, multi-machine value, it is subject to large uncertainties that stem from the inference of radiated energy and the calculation of coupled magnetic energy. τ_{CQ} provides a clearer physical value that is simpler to model but is insensitive to the target plasma or the energy balance.

Large uncertainties in the radiated energy emerge due to strong asymmetries associated with SPI injection and a lack of specialized diagnostics with toroidal resolution. JET's bolometery cannot yield tomographic inversions in mitigation experiments as its cameras are toroidally separated. Simulations employing phantoms suggest that the radiation location in a given poloidal plane can influence the inferred radiated energy obtained from one bolometer camera by up to 50% [3]. This has led to the development of an SPI specific bolometer analysis algorithm that infers a correction factor based on the location of radiation emission distribution from other diagnostics reducing the estimated uncertainty to 25% for a single toroidal plane. The recently revived KB1 bolometery system, comprising of four toroidally separated, poloidally identical lines of sight, is being incorporated into the new radiated energy analysis technique by providing a toroidal scaling function. Preliminary results indicate higher asymmetry for higher thermal energies that are particularly relevant to ITER as it may significantly alter inferences from previous f_{rad} measurements with high f_{th} [4].

Scans of auxiliary heating power with fixed plasma parameters, shown in Fig. 1, indicate a decreasing f_{rad} with increasing f_{th} as previously observed by the massive gas injection system on JET. Higher toroidal asymmetries may, however, have led to lower radiated powers being measured at the bolometer camera location, and thus a reduced f_{rad} would be measured at high f_{th}. With the simpler τ_{CQ} metric, a shorter τ_{CQ} was observed with increasing f_{th} implying a more resistive plasma after the thermal quench, most likely due to increased neon content assimilation. This is contrary to the trend observed with f_{rad} and unexpected based on previous studies [5]. To reduce the influence of thermal energy on ablation rate, a range of neon/deuterium mixtures were injected into a fixed plasma configuration. τ_{CQ} was found to be proportional to the injected neon quantity, irrespective of pellet size and thus the additional deuterium in the pellet. Pellets broken at launch performed as well as intact pellets unless a significant portion of the pellet arrived after the thermal quench and could not be ablated. This complete dataset provides a range of velocities, ablations rate and penetration depths for comparison with modelling.

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Scans using multiple barrels simultaneously investigated the superposition of pellets with variations in arrival times. Pellets from the 8mm and 4mm barrels resulted in small f_{rad} changes with variations in arrival time and no overall apparent trend. A timing scan for the 12.5mm and 8mm barrels gave an increase in τ_{CQ} of ~15-20% for simultaneous arrival and a doubling of density during the current quench. This shows promise for tailoring the neon and deuterium content for parallel RE avoidance and will be further investigated experimentally.

SPI operational space has been explored and optimised using f_{th} and τ_{CQ} as metrics. Trends based on τ_{CQ} indicate improved mitigation at higher τ_{CQ} and for simultaneous arrival of multiple pellets, both positive indicators for the ITER SPI system. The current uncertainties in radiated energy do not allow for quantification of f_{rad}, strongly motivating improved diagnostic hardware for future mitigation experiments. Ongoing threedimensional modelling efforts with synthetic diagnostics will be applied in the analysis of these discharges with a goal of generating a reliable mitigation efficacy metric[6].

References

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