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[REGULAR POSTER TWIN] Disruption mitigation by symmetric dual injection of shattered pellets in KSTAR

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ITER adopts a strategy that distributes radiated power evenly during the disruption mitigation and reduces the time to prepare pellets, using simultaneous multiple shattered pellet injections (SPIs)[1]. However, since there were no existing devices with perfectly symmetric SPIs, as planned in ITER[2], sufficient studies have not been conducted on the effects of simultaneous multi-injections. To verify the feasibility of the disruption mitigation strategy of ITER, KSTAR installed two SPIs with exactly same design at toroidally opposite locations as shown in figure 1[3]. Each SPI can use three barrels of different diameters to control the number of injected particles, selectively. The species used can vary deuterium, neon, argon, or their mixture depending on the mitigation purpose such as thermal load mitigation or runaway electron suppression/mitigation.

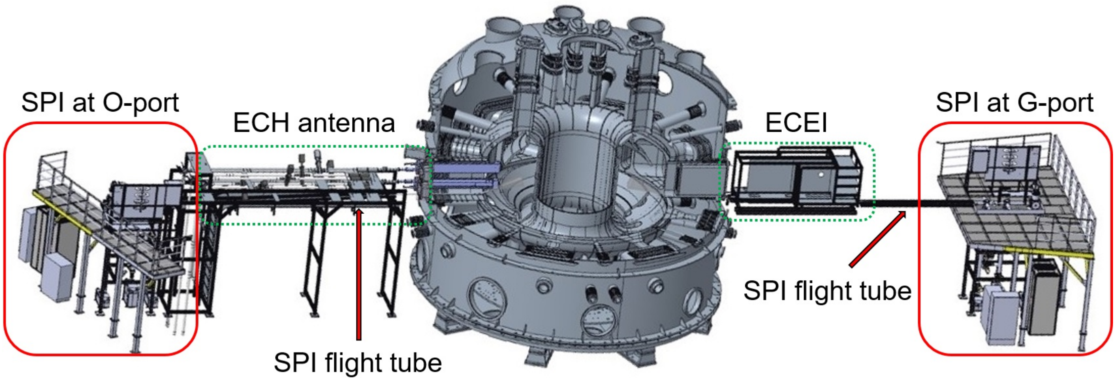

Figure 1: Toroidally symmetric dual shattered pellet injectors, which are 180 degree apart from each other, installed in KSTAR. They share the ports with ECE imaging and ECH antenna, respectively.

In 2019, we mainly examined the difference in disruption mitigation by intentionally changing the arrival times of two SPIs to assess possible jitter effect among multiple SPIs. As shown in figure 2a), the current quench rate changes proportionally as the time difference varies from several percent to several tens of percent of the thermal quench (TQ) duration (1˜2 ms). Through this, it was experimentally demonstrated that more energy can be radiated when multiple SPIs are injected simultaneously, as planned in ITER. The result resolved an ambiguity about the simultaneous multi-injections observed in previous experiments performed with two SPIs only 120 degree apart[4]. Moreover, the sensitivity to time difference identified by KSTAR experiments provided guidance in designing the ITER disruption mitigation system (DMS). The effect of multiple injections observed in KSTAR experiments is being analyzed using KPRAD, a radiation cooling code.
On the other hand, in the disruption mitigation process, it is also important to form a high plasma density to prevent the transfer of magnetic energy toward runaway electrons. For this study, a dispersion interferometer with short wavelength in 1064 nm was developed and installed to measure the density during the mitigation process that is one or two order higher than that of conventional plasma. In the case of dual SPIs, it was measured the peak density $1.2 \times 10^{21} m^{-3}$ near TQ end, which is almost twice the value of single SPI, as desired.

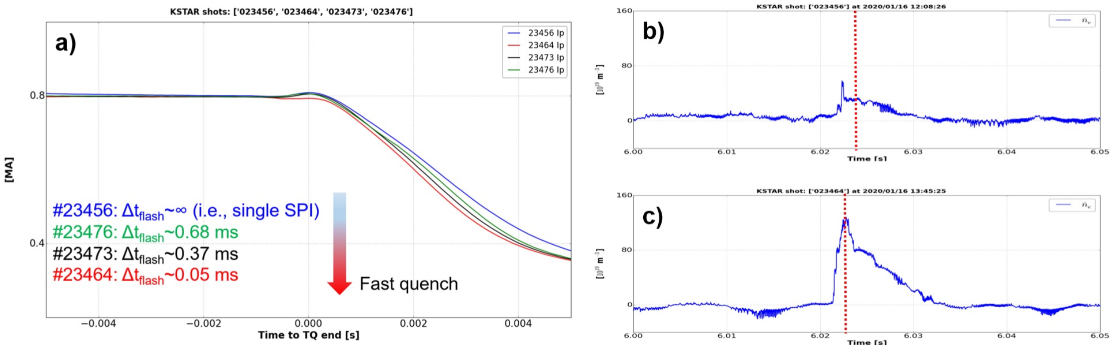

Figure 2: a) Current quench rates depending on the difference of arrival time between two SPIs, b) density rise during TQ in single SPI case (KSTAR #23456), and c) density rise during TQ in well-synchronized dual SPIs case (KSTAR #23464). Red vertical lines in b) and c) indicate the timing of TQ end.

Excessive particle injection of SPI and subsequent radiation create a strong MHD mode in the plasma. Conversely, this MHD mode has a significant impact on the behavior of the injected particles. As shown in figure 3, the well-synchronized dual SPIs exhibited much mild MHD mode than the asynchronized SPIs. Preliminary numerical analysis of the SPI-induced MHD mode (*not shown here*) indicated that ideally symmetric injection of two SPIs causes negligible odd perturbations (e.g., $n = 1$) and causes significant even perturbations (e.g., $n = 2$).

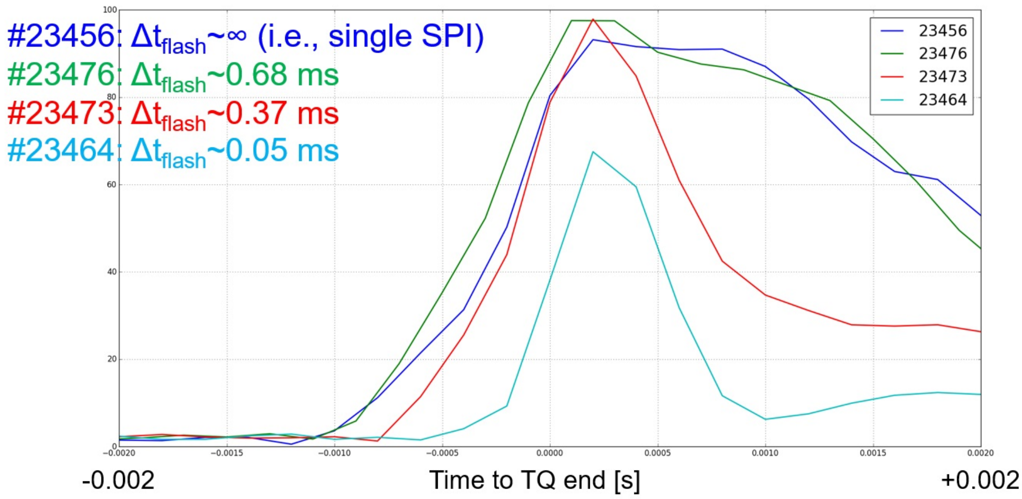

Figure 3: $n = 1$ MHD mode amplitudes during TQ depending on the synchronization of SPIs.

The disruption mitigation with SPI is complex phenomena depending on the plasma and SPI parameters. The study of the interaction with pre-existing MHD mode such as the cause of disruption is also important for establishing a realistic mitigation strategy. Among the various themes of DMS, we plan to focus firstly the multi-injections from different toroidal positions with varying the above-mentioned parameters as well as the multi-barrel injections from same poloidal/toroidal position in accordance with the plan of ITER DMS. For the purpose, the largest size barrel will be changed to middle size one to simulate ITER SPIs which have all same size barrels. It is expected to provide the data that underlie the design of the ITER DMS.

References:

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