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Design and Performance of Shattered Pellet Injection Systems for JET and KSTAR Disruption Mitigation Research in Support of ITER

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Shattered pellet injection (SPI) systems that form cryogenic pellets of low and high-Z impurities in a pipe-gun [1] for injection to mitigate disruptions have been fabricated and installed for use in thermal mitigation and runaway electron dissipation experiments on JET and KSTAR. These systems are to support disruption mitigation research for ITER and are based on an ORNL 3-barrel design for flexible pellet size and variable pellet composition studies [1]. The services for gas supply, vacuum, cryogenic cooling, and control are provided by the host institution with collaborative operation and experimental investigations organized by the host and through the ITER disruption task force [2].

The SPI systems for JET and KSTAR have a common feature of 3 different size pellets that are formed in-situ and collimated into a single injection line that enters the vacuum vessel. The pellets are fired by high pressure gas or mechanical punch and are shattered in stainless steel tubes with a 20-degree bend that are mounted inside the vacuum vessel of the tokamak, vertically on JET and horizontally on KSTAR. The JET installation shown in Fig. 1 has the unique feature of vertical SPI mounting and injection with the shatter plume aimed toward the inner wall to intercept known runaway electron (RE) beam locations generated from argon gas injection induced disruptions. Observations of the shattered pellet plume in plasmas on JET shown in Fig. 1 verify that the trajectory is as designed.

The JET SPI pellet sizes are 4.5, 8, and 12.5 mm diameter with lengths that are 30-50% longer. The two large sizes can optionally be operated with a mechanical punch for release of pure neon and argon pellets, that otherwise cannot be fired with gas alone. The control of the SPI is through a programmable logic controller programmed to automate the formation of the pellets and control vacuum components. Verification of the D2 propellant gas removal by the vacuum system was achieved by firing gas without a pellet and measuring that $< 0.25\%$ of the total gas fired ended up in the torus, showing excellent removal to prevent misinterpretation of the SPI performance by gas reaching the plasma before the pellet.

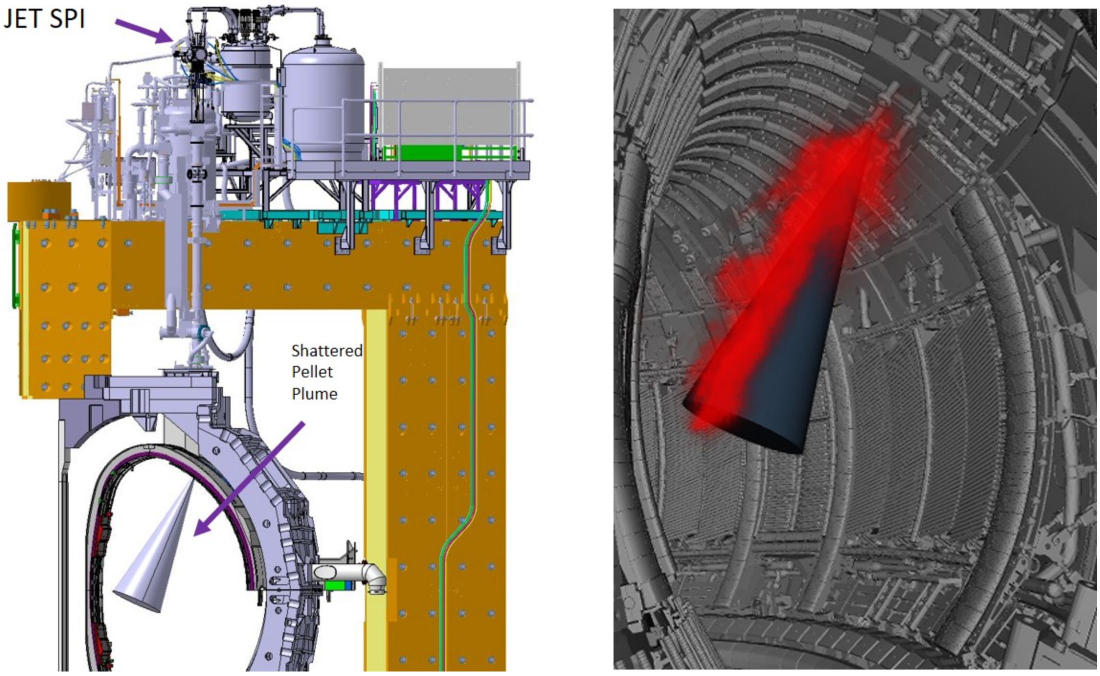

Figure 1: JET SPI installation on Octant 1 showing vertical installation with pumping and cryogenic infrastructure on top of JET. Time integrated fast camera image of neon fragments entering the plasma showing the plume and expected dispersion code

The KSTAR SPI installation described in Ref. [3] and shown in Fig. 2a has two identical 3-barrel SPIs that are mounted on the midplane with identical shatter tubes inside the vessel aimed to the plasma center after traversing a 20-degree shatter tube. Unlike the JET SPI that uses cold helium gas, these SPIs are cooled with a cryocooler that provides enough cooling to achieve 8 K pellet formation temperatures. Cooldown takes under 2 hours to be at pellet formation conditions, and it takes 5-15 minutes for the formation depending on the pellet size. The pellet sizes are 4.5, 7, and 8.5 mm with lengths that are 40% larger than the diameter. The pumping system and infrastructure were all provided by NFRI [3] and became operational in Nov. 2019. The performance of the propellant gas removal system was determined by firing the SPI with gas only into an empty torus where less than 0.1% of the gas was detected, but while the torus was being pumped. One of the key reasons for the KSTAR dual SPI installation is to investigate the performance of simultaneous injection of SPI pellets from ports on opposite sides of the machine. The identical SPI systems make this research possible as the systems have shown good synchronization between SPIs as shown in Fig. 2b where 7 mm D2 pellets fired from both SPIs arrive at their respective microwave cavities only 0.13 ms apart. Initial thermal mitigation experiments with neon-D2 mixtures have been performed with single and dual SPIs. These results show good assimilation of the pellet material into the plasma at the time of injection [4].

Installation and operation of these SPI systems has provided useful lessons learned in the implementation of this SPI technology and valuable experience in optimizing the performance of the formation and firing of the pellets. Experience on JET has shown a high reliability of pellet firing with only 1 failure to fire in over 150 attempts into plasmas since Sept. 2019. Punch operation with pure impurity pellets has also been especially reliable at firing pellets, but frequently results in broken pellets out of the injector .

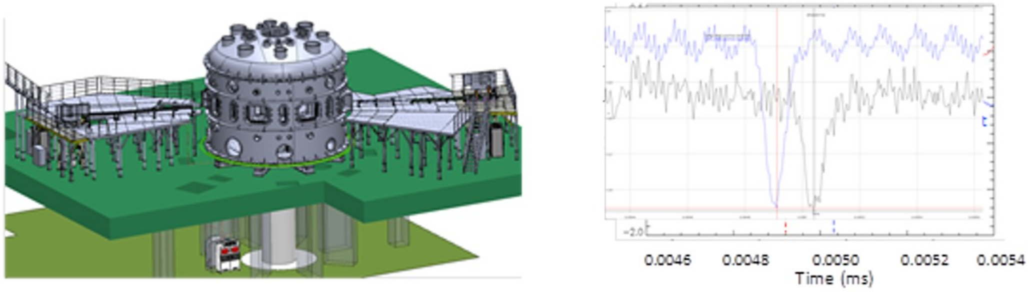

Figure 2: a.) Two SPI injectors (red) with identical guide and shatter tube geometries installed on the KSTAR G and O port flanges. b.) The microwave cavity signals for 7 mm D2 pellets fired simultaneously from both O and G ports showing 0.13 ms synchronization at the cavity location.

[1] L. R. Baylor, et al., Nucl. Fusion 68 (2019) 211.
[2] S. Jachmich et al., to be submitted to 28th IAEA Fusion Energy Conference (2020).
[3] S.H. Park, et al., ISFNT 2019, Fus. Eng. Des. 154 (2020) 111535.
[4] J. Kim et al., to be submitted to 28th IAEA Fusion Energy Conference (2020).

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