Progress of mitigating plasma disruption by the shattered pellet injection in EAST

ASIPP

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1. Introduction

- **Plasma disruption:** the sudden deterioration of plasma confinement and the discharge interruption caused by all kinds of MHD instabilities during the discharge process of tokamak
- **Deleterious effects from plasma disruption**
  - convection heat loads to the PFCs
  - poloidal halo currents generating mechanical stress
  - runaway electrons
- **Mitigation methods**
  - killer pellet injection (KPI)
  - massive gas injection (MGI)
  - Shattered pellet injection (SPI)

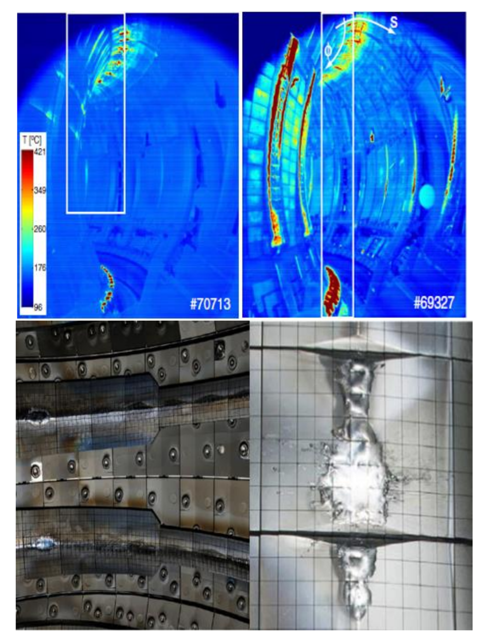

Fig.1 Thermal loads on PFCs and the wall melting resulting from runaway electrons striking during plasma disruption

2. Disruption mitigation system in EAST

2.1 MGIs and SPIs in EAST

- **MGIs Parameters**
  - Eddy current drive with good electromagnetic compatibility
  - Gas material: Ne, Ar, He, etc.
  - Response time: 0.15 ms
  - Impurity quantity: < 30 Pa·m^3/s (1-4 ms)

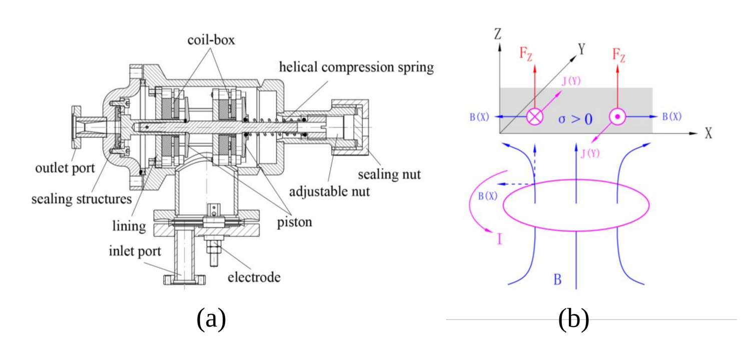

Fig.2.1 (a) Cross-section view of fast valve (b) Eddy-current repulsion in fast valve

- **SPI Parameters**
  - In-situ formation with the temperature of 8 K
  - Pellet material: Ne
  - Pellet size: D*L=5×7-15 mm (actual injected particles 9 - 14 Pa·m^3)
  - Pellet velocity: 100-400 m/s
  - Differential capability: $\frac{Q_{propellant}}{Q_{material}} < 3$ ‰

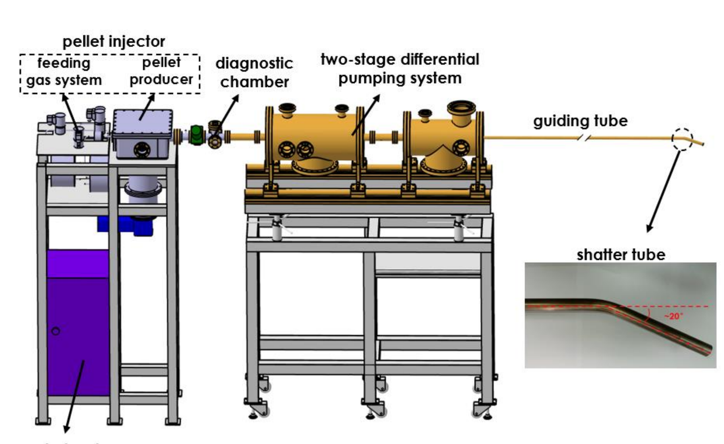

Fig.2.2 3D layout diagram of the SPI system

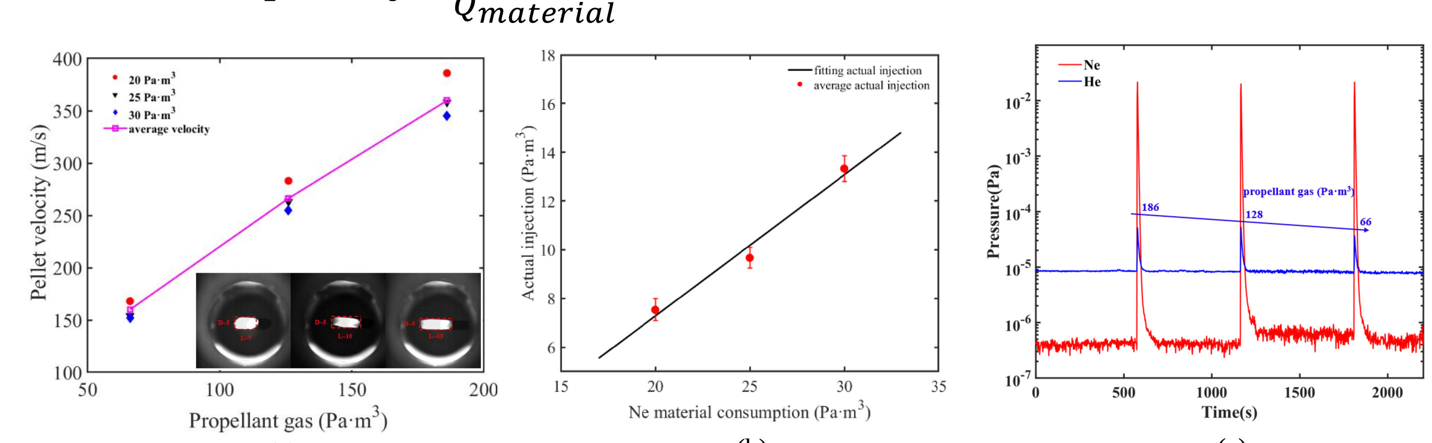

Fig.2.3 (a) Pellet velocities at different quantities of propellant gas (b) Actual injected amount of different Ne pellets with different Ne material consumption (c) Partial pressures of Ne and He in vacuum vessel

2.2 Experimental setup

- **Essential diagnostic**
  - Two MGIs and one SPI
  - Two CCDs: 10 kHz, 50 kHz
  - AXUV: 64 channels, 100 kHz
  - ECE: 32 channels, 1 MHz
  - Divertor probes and Mirnov probes : 50 kHz

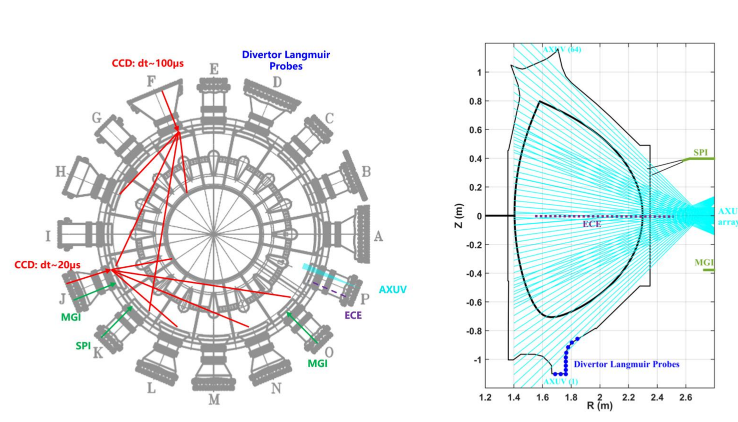

Fig.2.4 (a) Toroidal and (b) Poloidal views of essential diagnostics, MGIs and SPI

- **Shatter tube of SPI**
  - Position: ~20° tube (R, Z) = (2.5 m, 0.4 m), straight tube (R, Z) = (2.5 m, 0.4 m)

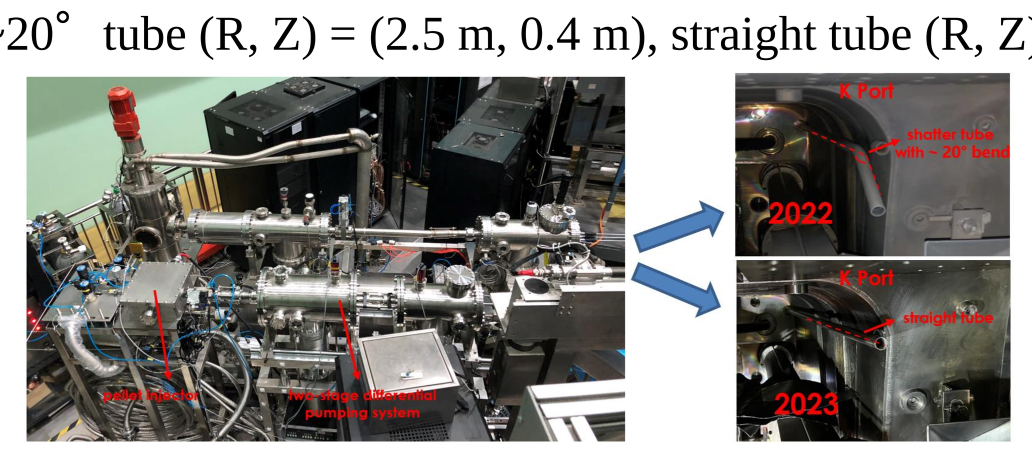

Fig.2.6 Images of the shatter tube (2022) and straight tube (2023) of SPI in vacuum vessel

3. Experimental results

3.1 First rapid shutdown using Ne SPI in EAST

- **Characteristics of rapid shutdown**
  - Ne SPI~13.2 Pa·m^3, 340 m/s
  - T_{pre-TQ}~4.5 ms, t_{TQ}~0.1 ms, t_{CQ}~10.8 ms
  - Penetration: edge radiation↑core radiation↑strong MHD
    TQ: radiation burst↑T_e collapse↓upward current spike
    CQ: rapid current decay↓

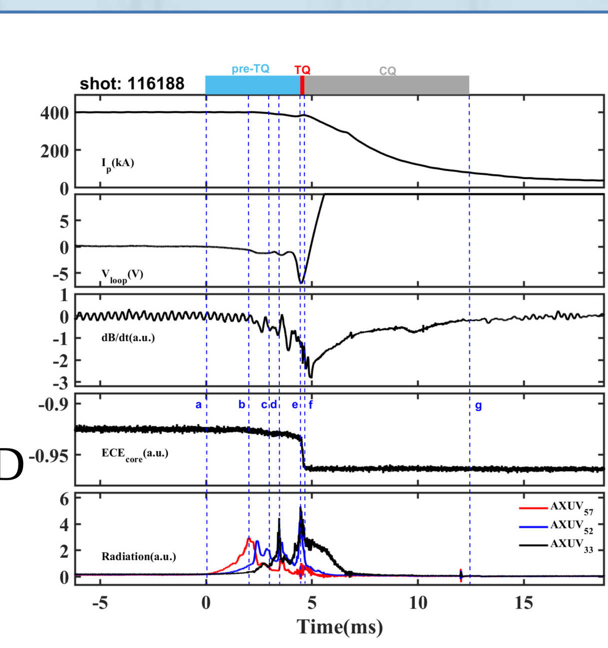

Fig.3.1 Time evolution of main plasma parameters during disruption mitigation with Ne SPI

- **Pellet Penetration process**
  - Small fragments: ablation, ionization, helical-structure movement and confined to the plasma edge
  - Larger fragments: pass through the LCFS into deeper plasma accompanied by ablation and poloidal transport along the closed magnetic surface

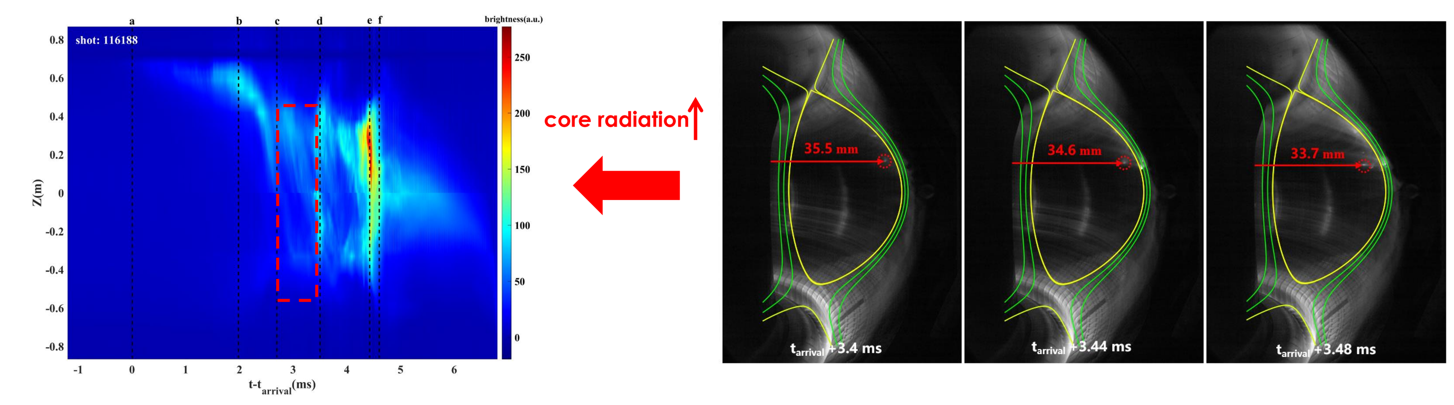

Fig.3.2 Radiation contour map for #166188 and penetration process of pellet fragments

3.2 Comparison of disruption characteristics between SPI and MGI

- Similar disruption characteristics, shorter cooling time, stronger core radiation and more uniform poloidal radiation distribution
- ~50% reduction for the peak T_e and ~40% reduction of q_t on the divertor

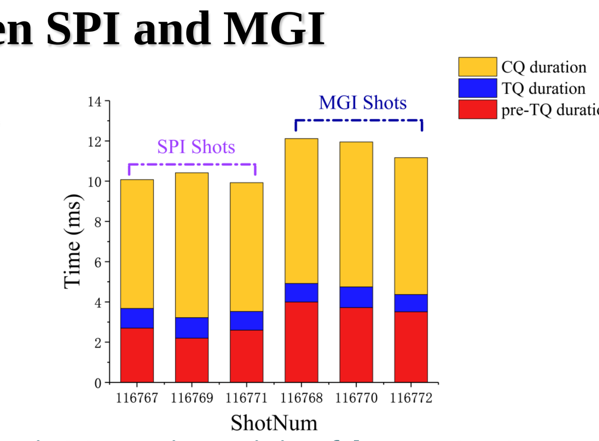

Fig.3.3 Duration statistics of the pre-TQ, TQ and CQ between MGI and SPI

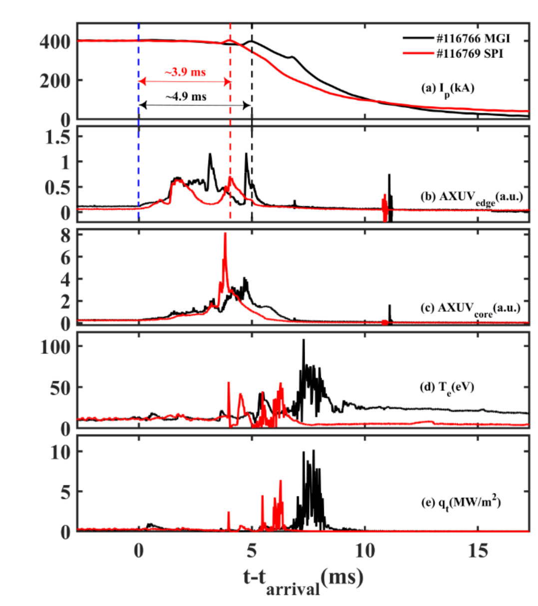

Fig.3.4 Comparison of plasma parameters triggered disruptions using SPI and MGI

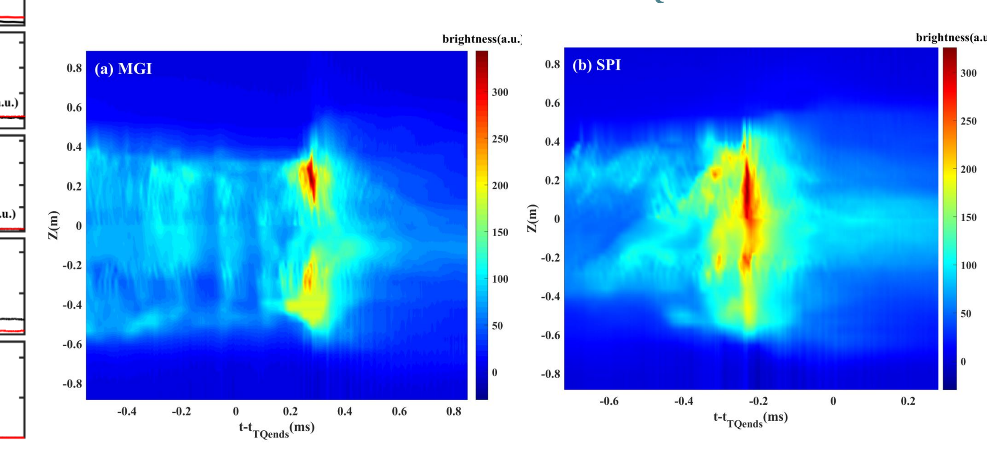

Fig.3.5 Radiation contour maps during TQ with MGI (a) and SPI (b)

3.3 Insufficiency shattered pellet injection (ISPI)

- **Characteristics of rapid shutdown**
  - Ne ISPI~13.2 Pa·m^3, 160 m/s
  - Similar disruption characteristics, t_{pre-TQ}~4.8 ms, t_{TQ}~0.059 ms, t_{CQ}~8.7 ms
  - Faster velocity leading to pellet fragmentation due to a slight curved tube
- **Comparison of disruption characteristics between SPI and PSPI**
  - Appear 'Tail', and also generate halo current, but smaller halo current for SPI
  - Easier to generate halo current using ISPI
  - PSPI with shorter t_{pre-TQ} (1.5-7 ms), longer t_{TQ} (0.05-0.15 ms) and t_{CQ} (4-5.5 ms)

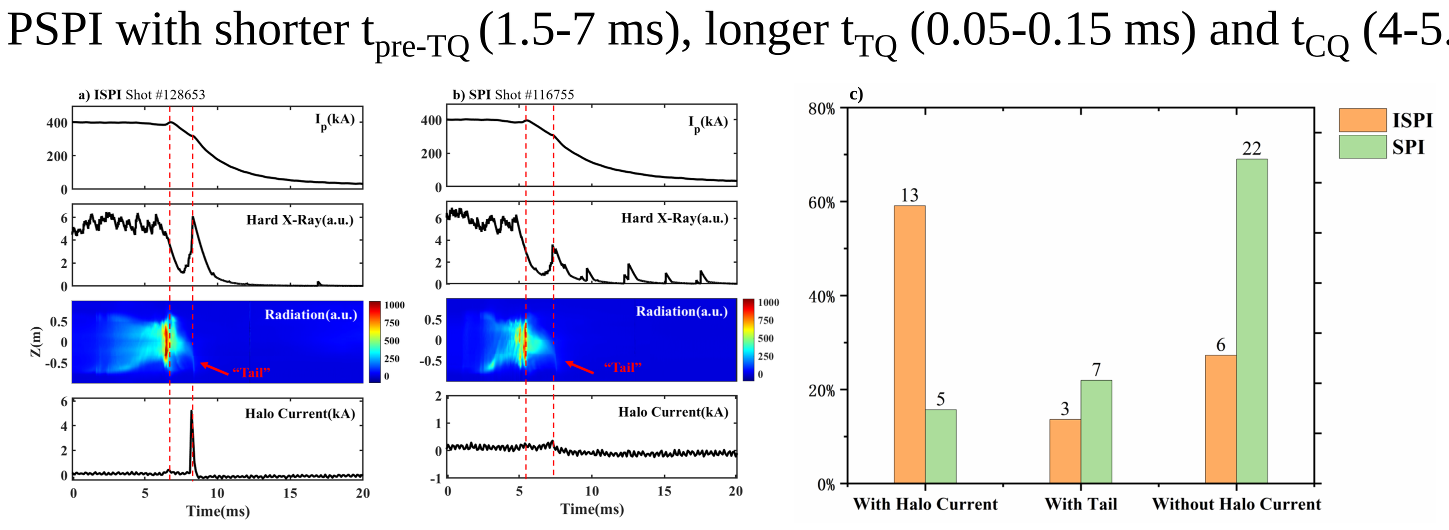

Fig.3.6 (a) (b) Time evolution of plasma current, Hard X-ray, radiation contour maps and halo current during disruption mitigation using ISPI and SPI (c) number statistics of w/o halo current and 'tail'

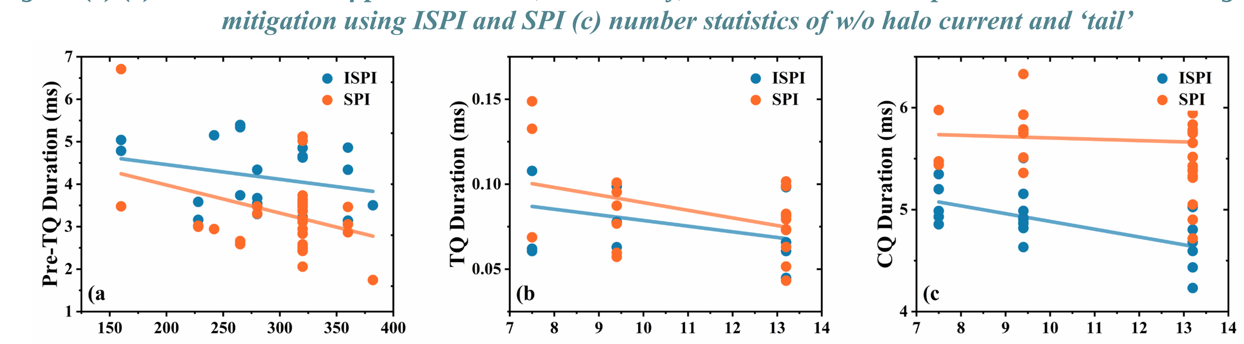

Fig.3.7 Duration statistics of the pre-TQ, TQ and CQ with different velocities and injected Ne particles

4. Summary & Outlook

- **Summary**
  - Small fragments are confined at plasma edge and larger ones pass through the LCFS into deeper plasma during fragments penetration process using SPI
  - Compared with MGI, shorter t_{pre-TQ}, stronger core radiation and more uniform poloidal radiation distribution, and better mitigation of T_e and q_t on divertor using SPI.
  - Compared with ISPI, shorter t_{pre-TQ}, longer t_{TQ}, t_{CQ}, smaller halo current using SPI; higher velocity and more injected particles for SPI and ISPI, shorter t_{pre-TQ}, t_{TQ} and t_{CQ};
- **Outlook**
  - Upgrades of the SPI system will be implemented to achieve the formation of mixed pellets using D_2/Ne or H_2/Ne
  - Disruption mitigation experiments with various SPI compositions

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