SAFE TERMINATION OF RUNAWAY ELECTRON BEAMS DURING MAJOR DISRUPTIONS BY SHATTERED PELLET INJECTION IN THE HL-3 TOKAMAK

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Major disruption in tokamak plasmas is one of the most critical challenges in fusion researches, as the disruptive event can severely deteriorate plasma confinement and even damage the plasma facing components (PFCs). A large fraction of runaway current may be formed due to the avalanche generation of runaway electrons (REs) in disruptions. REs reach energies up to 10s of MeV in multi-mega-ampere beams [1] and lead to significant localized damage on PFCs upon termination. Therefore, intensive research has been conducted over the past decades on mitigating the damage caused by RE beams during disruptions [2-4]. Safe termination of RE beams during major disruptions by the shattered pellet injection (SPI)-seeded high-Z impurities has been performed on the HL-3 tokamak.

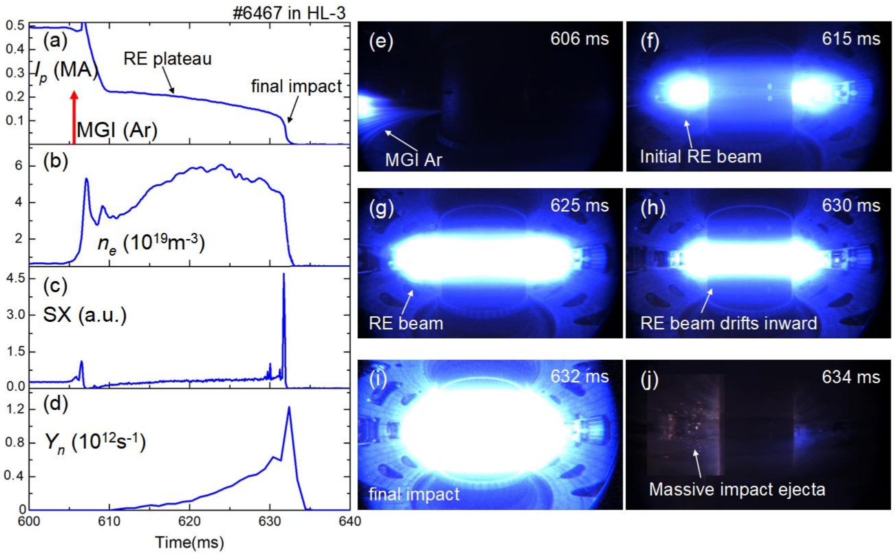

Fig.1 A typical disruption with RE plateau trigered by MGI-seeded Ar. (a)Total current. (b) Central line-averaged electron density. (c) Soft x-ray radiation intensity. (d) Neutron yield. (e)-(j) Temporal evolution of images obtained by a visible wide-angle camera. The red arrow indicates the time when MGI argon enters the plasma.

Experiments were carried out in deuterium plasmas in the HL-3 tokamak[4] with the following parameters: plasma current I_P = 0.5 MA, toroidal magnetic field B_t = 1.5 T and electron density n_e = (0.8-1.2) × 10^{19} m^{-3}. In this study, RE beams are created in the plasma with a limiter configuration using massive gas injection (MGI). A standard disruption with RE curent plateau is shown in Fig.1, where the temporal evolution of the main parameters is plotted for shot 6467. During the plasma current flat-top phase, about 2×10^{20} Ar atoms (twice the deuterium inventory of the pre-disruption plasma) are injected into the plasma by MGI at 606 ms to trigger the disruption. A runaway current plateau with ~0.2 MA is excited, as shown in Fig.1(a). The information of the generation and evolution of runaway beams is obtained by a visible wide-angle camera. It can be clearly observed that the runaway beam is generated at the core of the plasma and the minor diameter of the beam can be up to 0.2 m. The runaway beam gradually drifts towards the high field side of the plasma, and promptly impacts to the first wall at 632 ms. A high pulse occurs in the signals of SX and neutron yield, as shown in Fig. 1(c) and (d), implying that a strong collision between the electron beam and the first wall. A large amount of impact debris from the first wall component are ejected, as shown in Fig.1(j). The impact of runaway electron beams on the PFC is extremely dangerous for the safe operation of tokamaks. Therefore, the development of effective methods for the control or mitigation of disruption generated runaway electron beams is an urgent task.

In order to reduce or avoid the damage to the first wall by RE beams, SPI with high-Z material (Ar) is used for the safe termination of runaway current. The typical discharge of the runaway current formation is shown in Fig. 2, where the temporal evolution of the main parameters is plotted for shot 6476. About 5×10^{20} Ar atoms are injected into the plasma by SPI at 630 ms during the runaway current phase. After the Ar injection, both electron density and soft X-ray (SX) radiation significantly increase, while the neutron yield signal gradually decreased. The electron density increases from 4.0×10^{19} m^{-3} to 12.0×10^{19} m^{-3} (three times), indicating that the Ar pellet entered the RE beam and greatly increased the electron density. The increase in SX radiation shows an increase in RE bremsstrahlung, that is the collision damping of runaway electrons increases. The gradual decrease in neutron yield indicates that the electron beam is gradually weakening. The evolution of RE beam images obtained by a visible camera also illustrates this process, as shown in Fig. 2. No collision splash is generated at all during the final collapse phase of the RE beam, which suggests that the RE beam is safely terminated, that is, the runaway current is landed softly. The experiment presented in this paper shows an effective method for the safe termination of RE beams during major disruptions by the shattered pellet injection.

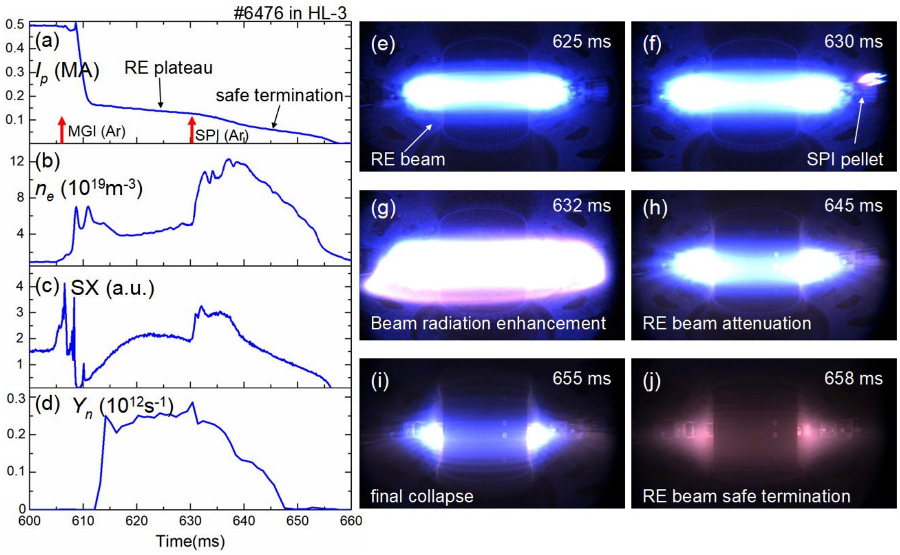

Fig.2 A typical disruption with RE plateau trigered by MGI-seeded Ar. (a)Total current. (b) Central line-averaged electron density. (c) Soft x-ray radiation intensity. (d) Neutron yield. (e)-(j) Temporal evolution of images obtained by a visible wide-angle camera. The two red arrows represent the time when argon injected by MGI and SPI enters the plasma, respectively.

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