Study of the shattered pellet injection on runaway current dissipation in the J-TEXT tokamak

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Introduction

Plasma disruptions are one of the major challenges for the present tokamak devices and the future ITER. REs generated in avalanche amplification are estimated to form up to 10 MA runaway current in ITER, which will cause huge damage to the plasma-facing components [1]. In these situations, the dissipation of runaway current becomes one of the critical problems. SPI has been a primary method for disruption mitigation in ITER, but it still needs more experimental results and analysis to prove the effect of SPI on runaway current dissipation. A series of subsequent experiments carried out in J-TEXT show that high-Z pellet successfully shorten runaway current duration and dissipate the runaway energy. Moreover, there is a positive correlation between the dissipation efficiency and the pellet velocity. The paper is organized as follows. The experimental setup is presented in section 2. The introduction of the experiment is shown in section 3. The effect of pellet velocity on RE dissipation is in section 4. Finally, section 5 gives the conclusions.

Experimental Setup

In the experiments, the disruptions are triggered by the massive gas injection system (MGI), and the runaway currents are dissipated by the shattered pellet injection system (SPI). The MGI valve is located at bottom of the port 9 of the vacuum chamber. The Ar SPI system [2] is located at the mid-plane of port 10. The Ar SPI system is located at the mid-plane of port 10. The argon pellet is formed with 5 mm diameter and 2~8 mm length at a temperature of 64 K, and the amount is from 1×10^{20} to 4×10^{21} atoms. Argon gas is used as the propellant gas, which can accelerate the pellet to 150–300 m/s. The Ne SPI system is located at the mid-plane of port

1. The neon pellet can be produced at a temperature of 15K, which has the same size as the argon pellet but contained about 1.7×10^{20} to 6.7×10^{21} atoms. The velocity of neon pellet can be adjusted to 150-350 m/s, which has a faster upper bound due to helium used as propellant gas. The pellet is shattered before entering the plasma by impacting a strike plate situated at the entrance to the tokamak vacuum chamber. The shattered pellets need about 30 ms to arrive at the plasma edge. The Schematic view of related diagnostics on J-TEXT is shown in figure 1.

Experimental results

A typical discharge of runaway current dissipation by argon SPI is shown in figure 2. The initial plasma current was I_P =180 kA. Runaway current will be easily formed when the toroidal field is larger than 2 T, thus the toroidal field was set to B_T=2.2 T. A high electron density will suppress the generation of REs, thus the line average electron density in the experiment was set to n_e~1×10^{19} m^{-3}. About 4×10^{19} atoms of argon gas were injected by MGI, and the gas arrived at the plasma edge after 2 ms. About 100 kA runaway current was formed at about 4 ms after MGI triggered. The SPI system was triggered at 20 ms before MGI to let the shattered argon pellets arrive after the RE beam was totally formed. The quantity of argon atoms in the pellet was about 2.1×10^{21}. The velocity of pellet was 251 m/s, and the shattered pellets arrived at the RE beam at about 8 ms after MGI was triggered.

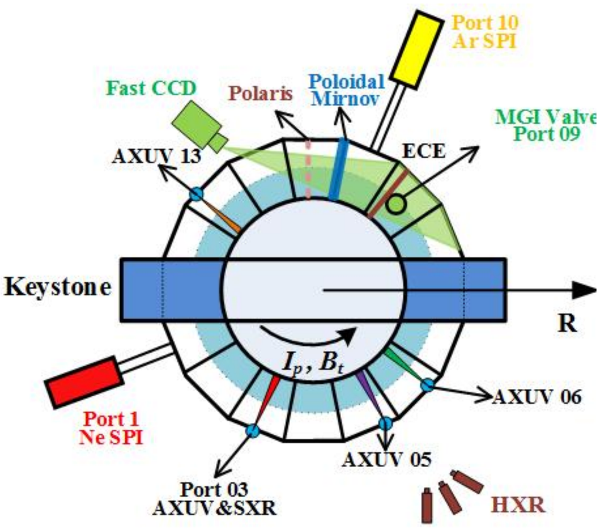

Figure 1. The schematic view of related diagnostics on J-TEXT

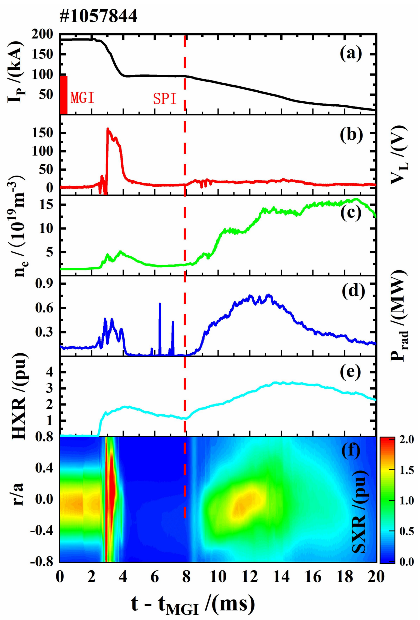

Figure 2. Typical shot based on runaway current dissipation experiment of SPI system

The argon impurities penetrated the RE beam and caused an increase in electron density due to their ionization in figure 2(b). The quick decay of the runaway current and increase of thermal radiation intensity was found in figure 2(a) and (d), showing the dissipation effect of impurities on the runaway current. The following phase was the dissipation phase. The runaway current dissipation rate was about 10 MA/s. The loop voltage induced by the current decay was stable during the dissipation phase, which can be seen in figure 2(b). It indicated that the induced toroidal electric field was about 3 V/m. The increase of hard X-ray radiation intensity in figure 2(e) showed the enhancement of RE loss. From the profile of soft X-ray radiation 2(f), a radial displacement of the runaway current towards the low field side during the dissipation phase was founded. The soft X-ray radiation profile also can be used to estimate the radius of RE beam [3].

Effect of pellet velocity on dissipation

The dissipation of runaway current by massive gas injection has also been achieved on J-TEXT. It shows that 2×10^{21} argon gas injected by MGI can lead to a 20 MA/s runaway current dissipation rate, which is larger than the 10 MA/s runaway current dissipation rate achieved by pellet with 2.1×10^{21} argon atoms. A possible reason is the sublimation of shattered pellets during the dissipation phase is incomplete. One way to make pellet ablation more complete is to increase the pellet velocity, which would result in more and smaller fragments and a larger contact area with REs beam. Therefore, we fixed the size of the pellet to ensure the same amount of impurity injection, which is about 3×10^{21}. At the same time, the pellet velocity has been scanned from 200-300 m/s to study its influence on the dissipation effect. Figure 3(a) shows the effect of pellet velocity on impurity assimilation rate. It can be found that with the increase in pellet velocity, the impurity assimilation rate is significantly improved from 4% to 10%. As the impurity assimilation rate increases, more energy stored in the runaway current is dissipated through the synchrotron and bremsstrahlung radiation losses, eventually leading to rapid decay of runaway current. Here, a simplified definition $\frac{dI_{RE}}{dt} \approx -\frac{\Delta I}{\Delta t}$ is given to represent an average rate over the whole dissipation phase. The value of runaway current I_{RE} is calculated at 0.405s when the runaway current plateau is stable. ΔI is the plasma current decay from 80% to 20% and Δt is the duration of ΔI. There is a positive correlation between the I_{RE} dissipation rate and pellet velocity, which can be seen in figure 3(b). When pellet velocity approaches 300 m/s, the IRE dissipation rate increases to about 20 MA/s, which shows the Ar SPI has a similar effect to Ar MGI. Similar results are also found in Neon SPI experiments, which can be shown in figure 3(c). It indicates that it is useful to increase pellet velocity to improve the dissipation efficiency of runaway current.

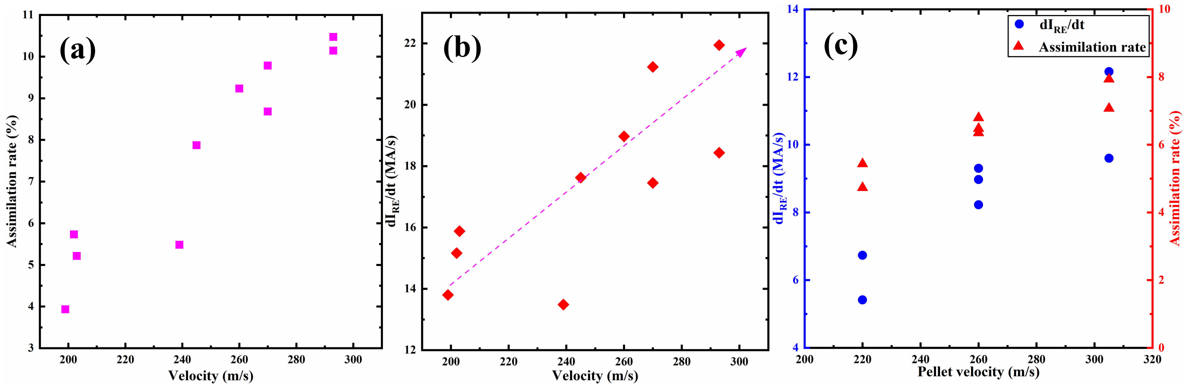

Figure 3. (a) The effect of Ar pellet velocity on impurity assimilation (a) and REs beam decay rate (b); The effect of Ne pellet velocity on impurity assimilation and REs beam decay rate (c).

Summary

In this paper, Ar SPI and Ne SPI have been used to dissipate runaway current. The experimental results show that the high Z impurity like argon and neon has a successful dissipation of the runaway current by increasing the thermal radiation. However, in the SPI shot, the incomplete ablation of the pellet will result in a poor runaway current dissipation rate, which would be low than 10 MA/s in J-TEXT. It indicates that the factor limiting the dissipation efficiency of runaway current is the ablation rate of solid pellets in plasma. One method to improve ablation rate is to increase pellet velocity. It is proved that there is a positive correlation between the dissipation efficiency and the pellet velocity. As the increase of pellet velocity, the impurity assimilation rate would be improved, which eventually leads to a better dissipation efficiency. Especially in J-TEXT, when the pellet is accelerated to about 300 m/s, the Ar SPI would have a similar effect of runway current dissipation to the Ar MGI.

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