CHARACTERISTICS OF RUNAWAY ELECTRON LOSS IN THE INTEGRATED COMMISSIONING OF JT-60SA

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Spatiotemporal characteristics of runaway electron (RE) loss on plasma facing components (PFCs) have been identified in the integrated commissioning of the largest superconducting tokamak JT-60SA, which is on a scale comparable to ITER and DEMO. The RE losses are detected by neutron flux monitors (NFMs) through photoneutrons caused by collision of REs with PFCs in the large superconducting tokamak for the first time. Because the NFMs provide a lot of observational information on REs in the similar environment, the observed spatiotemporal characteristics will contribute to development of avoidance or mitigation methods of the local RE losses in ITER and DEMO. Furthermore, the usefulness of the NFM indicates its potential application to RE diagnostics in the non-activation phases of ITER and DEMO.

1. INTRODUCTION

Runaway electrons (REs) are generated by a strong toroidal electric field especially at tokamak plasma startup or disruption. Intense heat loads caused by local RE losses on the plasma facing components (PFCs) are one of the crucial issues in terms of machine protection for ITER and DEMO. During the establishment phase of safe plasma operation scenarios in the experiment, the REs would be generated and lost on PFCs. Consequently, understanding of characteristics of the RE generation and loss in a large superconducting tokamak is important to consider avoidance or mitigation methods of the local RE losses in an initial plasma operation phase of ITER and DEMO. JT-60SA is the currently largest superconducting tokamak in the world and comparable in scale to ITER and DEMO. In the JT-60SA integrated commissioning, safe operation scenarios were developed for the largest tokamak plasma, while many plasma disruptions occurred [1]. During and before the plasma disruption, RE losses were observed. The objective of this study is to characterize the RE losses in the integrated commissioning of JT-60SA for contribution to development of the safe plasma operation scenarios in the commissioning phase of ITER and DEMO.

2. DETECTION METHOD OF RE LOSS

When REs hit PFCs, gamma-rays are generated as bremsstrahlung. Although gamma-ray diagnostics are useful to measure RE losses, there was no dedicated gamma-ray diagnostics installed in JT-60SA at the integrated commissioning phase. The gamma-rays produce photoneutrons via nuclear reaction with atoms in in-vessel components. In the integrated commissioning of JT-60SA, only H or He gases are used for plasma production. Therefore, no fusion neutron is produced in the plasma. Thus, in this study, we used neutron flux monitors (NFMs) with ^{235}U fission chambers at P-10 and P-18 ports (160 degrees apart at a toroidal angle) to indirectly detect RE losses on PFCs via measurement of the photoneutrons.

3. RE LOSS DURING AND BEFORE THE PLASMA DISRUPTION PHASE

Before the safe operation scenarios are developed in actual experiments, disruptions could occur especially in the commissioning phase of tokamaks including ITER and DEMO. In the integrated commissioning of JT-60SA, three types of plasma disruption are observed: a) vertical displacement event (VDE), b) radiative disruption and c) control failure of the plasma equilibrium control scheme [1]. In the VDE case a), bursty signals of neutron counting rates are observed when the vibrated plasma hits the PFCs. In the radiative disruption case b), the typical discharge is shown in Fig. 1. Just after MHD activities with toroidal mode number $|n| = 1$ grows rapidly, bursty signals of neutron counting rates are observed, indicating that REs are lost significantly by the MHD activity. In the previous study, this MHD activity is considered as a tearing mode based on measured soft-X ray signals showing a radial tearing parity structure [1]. Therefore, a possible loss mechanism is an exhaust of REs by magnetic reconnection of a tearing mode [2]. In the previous study, it is considered that the control-failure-type disruption is triggered by a tearing mode [1]. Its intense non-axisymmetric magnetic fluctuation leads to the failure of the plasma equilibrium control scheme. In the control failure case c), observed characteristics of RE losses are found to be the same as those in the radiative disruption case. In conclusion, the cause of RE losses in the disruption phase is summarized as VDEs or tearing modes.

Even before the plasma disruption, RE losses are detected as shown in Fig. 2. In the time period shown in this figure, I_p is almost constant at 0.3 MA and the plasma position is stationary. A magnetic perturbation is weaker than 3×10^{-7} T, which corresponds to < 1/1,000 of that in the disruption case shown in Fig. 1. Nevertheless, neutron counting rates increase gradually, indicating the RE loss increases continuously. The increase rate of the neutron counting rates is roughly consistent with an estimated RE avalanche growth rate. A seed of the REs is found to be generated before the plasma disruption. This is an important observation since the inductive toroidal electric field for the plasma breakdown is low (~0.15 V/m) due to a reduced coil voltage operation in JT-60SA [3]. This condition is similar to those in ITER and DEMO. The RE seeds might be generated by Dreicer acceleration due to electron cyclotron heating used for the plasma breakdown [3] and/or low plasma density. After the plasma operation scenarios were developed, such RE loss was not detected.

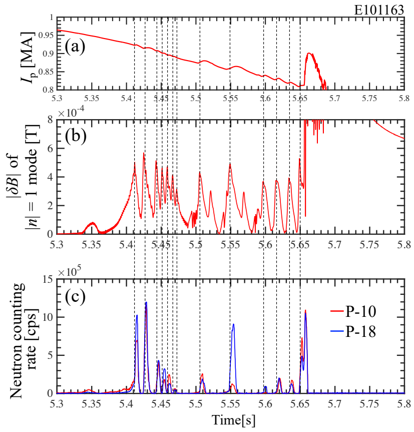

FIG. 1. Time evolution of (a) I_p, (b) the magnetic fluctuation amplitude $|\delta B|$ of the toroidal modenumber $|n|$ = 1 and (c) the neutron counting rates measured with NFMs at two positions in a typical discharge of the radiative disruption. Bursty neutron counting rates indicating significant RE losses are observed at MHD activities.

4. LOCALITY OF THE CONTINUOUS RE LOSS

It can be expected that the neutron counting rate increases when the RE loss location on PFCs becomes closer to the NFM location. If spatial distribution of the RE loss is non-uniform, a magnitude relation of the neutron counting rates between two NFMs can vary. The observed magnitude relation is found to have a correlation with the plasma vertical position when the REs are continuously lost. Figure 3 shows a typical discharge where the plasma moves vertically due to VDE. The neutron counting rate at P-18 becomes larger than that at P-10 when the plasma vertical position is higher. The vertical position Z of the NFM at P-18 ($Z \sim$ -0.47 m) is higher than that at P-10 ($Z \sim$ -1 m). The observed change of the magnitude relation indicates a change of a vertical RE loss location on PFCs because in this discharge there is no intense MHD mode which can change the loss location, such as the mode shown in Fig. 1. Namely, the continuous REs are found to be lost locally in the poloidal direction in JT-60SA. NFMs will be also installed in ITER and DEMO, where available spaces for plasma diagnostics are limited. Since a lot of observational information on the REs was obtained with the NFMs in the similar environment, the NFMs has potential for RE diagnostics used in the non-activation phases of ITER and DEMO.

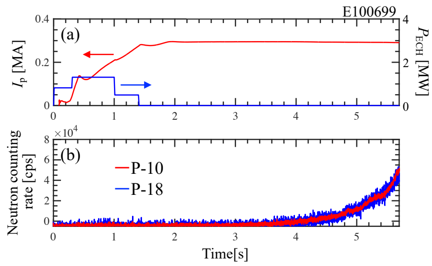

FIG. 2. Time evolution of (a) I_p, ECH injection power P_{ECH} and (b) the neutron counting rates measured with NFMs. The continuous RE loss is detected before the plasma disruption.

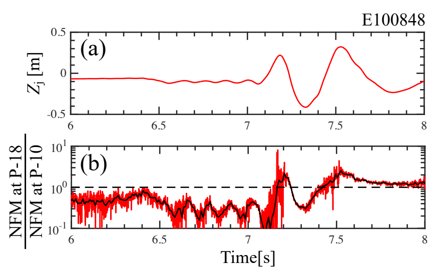

FIG. 3. Time evolution of (a) vertical position of the plasma current centroid Z_j and (b) a ratio of the two neutron counting rates. The ratio has a correlation with the plasma vertical position.

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