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Study of Plasma Collapse in Plasma Current Ramp-Down Phase of Tokamak and Helical Devices

トカマク・ヘリカル装置における電流ランプダウン時のプラズマコラプスの比較

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We investigated the current behavior of JT-60U and LHD in the current ramp-down phase. In the current ramp-down phase in the 2008 JT-60U experimental campaign, the positive spikes of plasma current were observed in the end of many current ramp-downs. The positive spike of plasma current was generated by the rapid change of electron temperature profile. On the other hand, in the LHD discharges with the net toroidal current by unbalanced Neutral Beam Injection (NBI), the positive spike of plasma current is not observed at the end of current ramp-down.

1. Introduction

In tokamak device, the plasma current is necessary to maintain MHD equilibrium, and the electromagnetic energy of plasma in large tokamak device such as ITER and demo-reactors is huge. Therefore, the time change of plasma current has an impact into device such as vacuum vessel. Because the damage generated in the device is large during the disruption, the study of determination mechanism and control method of plasma current decay in disruption has been performed [1].

On the other hand, when the plasma discharge terminates without the disruption, it is necessary that plasma current decrease to zero. In the end of current ramp-down phase, it is expected the destruction of the MHD equilibrium and rapid release of electromagnetic energy. However, the early research for the plasma behavior in the end of current ramp-down phase is poor. In this study, we investigate the behavior of plasma parameter during the current ramp-down phase of JT-60U in order to clear up the influence of dissipation of MHD equilibrium on the termination of plasma discharge. And we investigated the behavior of plasma parameter during the current ramp-down phase of LHD in order to compare the results in tokamak and helical devices because the plasma current is not necessary to maintain the MHD equilibrium in the helical device.

2. Current Ramp-Down Phase in the JT-60U

Fig. 1 shows the developmental rate of positive spike of plasma current during current ramp-down in 2008 JT-60U experimental campaign. As shown in Fig. 1, it was found that the positive spike of plasma current occurred in many current ramp-down phases. However, the reason why that the positive spike of plasma current occurred during the current ramp-down is not understood.

In order to investigate the behavior of plasma around the on-set time of the positive spike of the plasma current, we paid attention to the end of current ramp-down phase. Time evolution of the plasma current, the electron temperature profile, and the safety factor of plasma surface in the

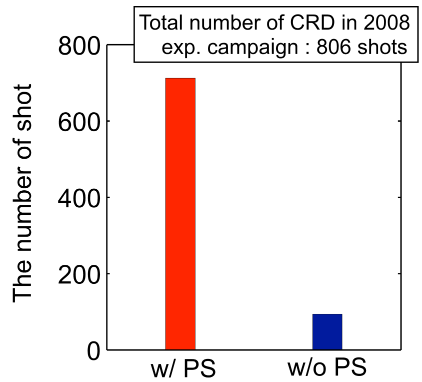

Fig. 1 Developmental rate of the positive spike of plasma current during current ramp-down phase in the 2008 JT-60U experimental campaign.

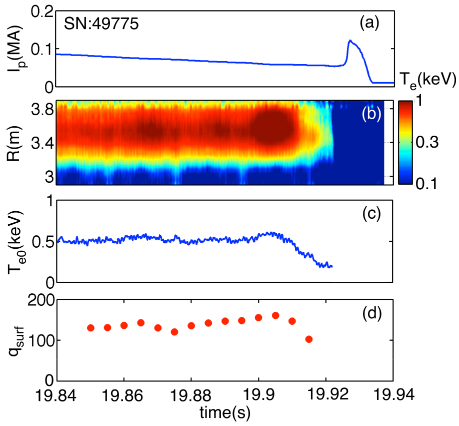

Fig. 2 Typical Waveforms of (a) I_p, (b) T_e profile, (c) T_e at plasma center, T_{e0}, and (d) q_{surf} in the end of current ramp-down phase of the JT-60U.

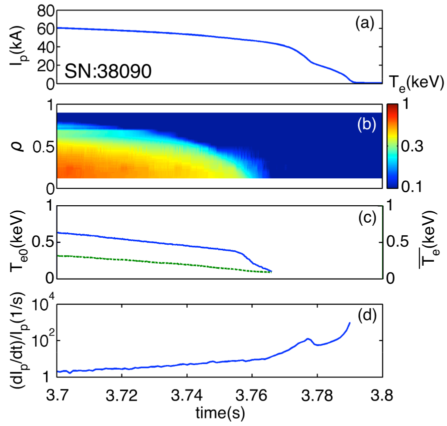

Fig. 3 Time evolution of (a) I_p, (b) a radial profile of RT_e, (c) RT_e at plasma center, an areal mean of RT_e profile, and the current decay rate normalized by I_p.

current ramp-down phase of the JT-60U are shown in Fig. 2. T_e profile is measured from an ECE diagnostic system. Because q_{surf} cannot be evaluated by using the magnetic sensors' signals and the MHD equilibrium calculation code, the safety factor of plasma surface is evaluated from ECE measurement and the following equation [2]:

$$q_{surf} = 2\pi a^2 B_t / \mu_0 I_p R_0 \,. \qquad (1)$$

Here B_t and a are the toroidal field and plasma minor radius, respectively. Supposing that the plasma edge is the boundary of ECE measurement, the S is evaluated. As shown in Fig. 2 (b), T_e gradually decreases before the positive spike of plasma current. q_{surf} gradually decreases just T_e decreases as shown in Fig. 2 (c). The rapid decay of T_e occurs after T_e at plasma center becomes about 200 eV, and the positive spike of plasma current is observed. The rapid decay of T_e profile is observed at the disruption phase in many devices before the positive spike of plasma current. The above results suggest that the disruption occurs during the current ramp-down phase in the JT-60U discharges. As shown in Fig. 2 (d), q_{surf} decreases just before the rapid decay of T_e profiles. That means the plasma at the time, when the positive spike is observed, is more favorable for MHD equilibrium than that before the appearance of the positive spike of plasma current. This result suggests that disruption is triggered by a growth of instability in the JT-60U.

3. Current Ramp-down Phase in the LHD

In the LHD, net toroidal current is not necessary to confine the plasma because the helical devices always keep magnetic surfaces only by the external coils. In this paper, we focus on the current termination of the discharges maintained by the unbalance of NB injection. In order to investigate the reason why the positive spike of plasma current is not observed just before the rapid decay of the plasma current in the current ramp-down of the LHD, we evaluated the time evolution of radiation temperature, RT_e, profile by using ECE diagnostic system. It should be noted that RT_e means the electron temperature that is not considered about the effect of optical thickness of ECE measurement here. Fig. 3 shows the time evolution of I_p, a radial profile of RT_e, RT_e at the plasma center, an areal mean of RT_e profile, and the current decay rate normalized by I_p value, $dI_p/dt/I_p$. In Fig. 3, the rapid decay of the plasma current starts at t = 3.764 s when RT_e at the plasma center is less than 100 eV. However, the positive spike of plasma current was not observed before the rapid decay of plasma current in the LHD. During the rapid decay of plasma current, RT_e and I_p slowly decrease comparing with the rapid decay of plasma current in the JT-60U. These results suggest that the rapid decay of plasma current in LHD is not triggered by a strong MHD instability.

4. Summary

The behavior of plasma current during the current ramp-down was investigated in the JT-60U and the LHD. The disruption triggered by a strong MHD instability was observed in many current ramp-downs of the JT-60U. On the other hand, in the end of the LHD discharge, the positive spike of plasma current was not observed before the rapid decay of plasma current occurred. These results suggest that the rapid decay of plasma current in LHD is not triggered by a strong MHD instability despite the JT-60U. In future work, we need to investigate the behavior of plasma ramp-downs in which the positive spike of plasma current was not observed to investigate the determination mechanism of disruption in the end of current ramp-down phase.

Reference

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