Effect of Externally Applied Resonance Magnetic Perturbation on Current Decay during Tokamak Disruption

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Disruption is one of the most critical issues in tokamaks. A resonance magnetic perturbation (RMP) coil system will be installed in future tokamaks such as the International Thermonuclear Experimental Reactor to mitigate edge localized modes. In this study, the effect of RMP on tokamak disruption was investigated using the small tokamak device HYBTOK-II. It was found statistically that an externally applied RMP leads to faster current quench during disruption.

Keywords: disruption, current decay, resonance magnetic perturbation, small tokamak device, HYBTOK-II

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Control of tokamak disruption is one of the most critical issues for establishing long pulse and/or steady state discharges in next-generation fusion devices such as the International Thermonuclear Experimental Reactor (ITER) [1]. The mitigation of edge localized modes (ELMs) is also important because the pulse heat load on a divertor plate induced by ELMs is thought to exceed the material limits. Recent experimental results in the DIII-D tokamak and others [2] suggest that applying resonance magnetic perturbation (RMP) to tokamak plasmas may be one of the most promising methods of ELM mitigation. However, the influence of RMP on disruption has not been investigated yet. In this study, we investigated the effect of RMP on the current decay during disruption in the small tokamak device HYBTOK-II at Nagoya University.

The major and limiter radii of HYBTOK-II are 40 cm and 11 cm, respectively [3]. Hydrogen is used as the working gas in experiments, and the discharge duration is 20 ms. The RMP coils in HYBTOK-II consist of two sets of local helical coils, which have an insulated gate bipolar transistor inverter power supply [3], as shown in Fig. 1. Two types of coils (α,β) are installed outside the vacuum vessel at the odd-numbered toroidal sections in Fig. 1. The poloidal number of the RMP coils m is 6 determined by the shape of the local helical coils. Figure 1 (c) shows a schematic of how the RMP coils are connected by illustrating only four wires of the coils at the outer mid-plane of the torus when the toroidal mode number n is 1. The current direction is shown by red and blue arrows for the α and β coils, respectively. Two current circuits, the A and B routes, are shown by solid and dashed lines, respectively.

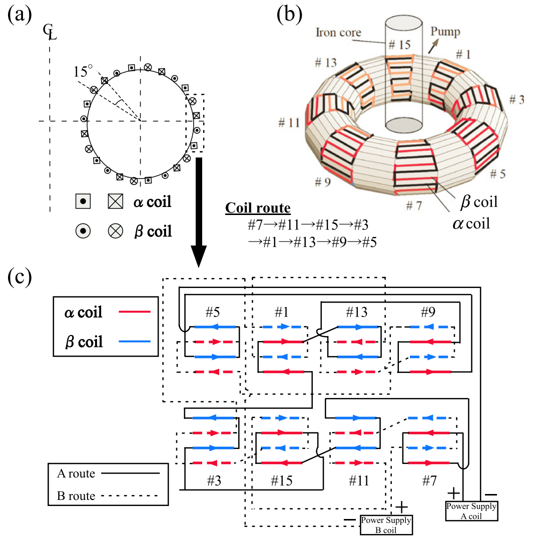

Fig. 1 RMP layout drawing in HYBTOK-II tokamak. (a) Poloidal cross section view, (b) bird's eye view, (c) schematic of connection of RMP coils (n = 1).

The toroidal number n can be varied from 1 to 4 by changing the combination of α and β coils and their current direction. The maximum coil current is 150 A. The intensity of the RMP is 5 G at the normalized radius $\rho = 0.75$, where the poloidal magnetic field is 170 G. The RMP frequency is 1 kHz.

The typical waveforms of disruptive discharge in the HYBTOK-II are shown in Fig. 2. Disruption was induced by the ramping up of the plasma current I_{p} to reduce the safety factor of the plasma surface q_{a}. A positive spike in the plasma current was observed at q_{a} ~3, and then a current quench started [4]. Growth of the m/n = 3/2 tearing

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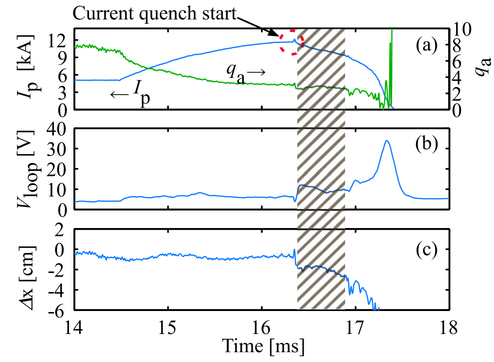

Fig. 2 Time evolution of (a) plasma current I_p and plasma safety factor q_a, (b) plasma loop voltage V_{loop} and (c) distance from horizontal plasma current centre Δx.

mode was observed just before the disruption. It was concluded that the disruption was due to a nonlinear interaction between the m/n = 1/1 internal kink mode and the m/n = 3/2 tearing modes [4]. Further, it was found experimentally that the RMP does not affect the growth of the m/n = 3/2 tearing modes. The data in the hatched area shown in Fig. 2 were used for the analysis, because the plasma center and plasma cross-section changed slightly during the time period. The current decay rate, $\Delta I_p/\Delta t$, was evaluated by the linear approximation of the plasma current. The RMP was introduced from $t = 13 - 20$ ms.

Figure 3 show histograms of the current decay rate $\Delta I_p/\Delta t$ during the current quench phase of the disruption without RMP and with RMP at $n = 1$, and at $n = 3$, respectively. In each case, 70 discharge shots in the same experimental condition were used to obtain the histograms of the $\Delta I_p/\Delta t$. The histogram was clearly changed by the introduction of RMP. The averaged $\Delta I_p/\Delta t$ was -3.62 kA/ms without RMP, -4.66 kA/ms with RMP at $n = 1$, and -4.20 kA/ms with RMP at $n = 3$. The averaged $\Delta I_p/\Delta t$ with RMP becomes negatively larger than that without RMP, the peak at $-3 \sim -4$ kA/ms in the histogram without RMP shifted to $-5 \sim -6$ kA/ms when RMP was applied for $n = 1$. Further, it is found that the sharp peak disappears and the profile of the histogram becomes broader with RMP for $n = 3$.

Next, we investigated the effect of the RMP on the plasma during disruption. Figures 4 (a) and (b) shows the Poincaré plots of the calculated magnetic line traces with RMP for $n = 1$ and 3, corresponding to Figs. 3 (b) and (c), respectively. As shown in Fig. 4 (a), m/n = 6/1 RMP generates an ergodic magnetic structure. Because the resonance surface of m/n = 6/1 is located at the edge of the plasma column, the effect of the RMP with m/n = 6/1 is localized in the peripheral region ($\rho > 0.9$). This indicates that even such a small deformation of the magnetic structure at the peripheral region due to the application of RMP strongly influences the current decay rate of the current quench. On the other hand, the RMP with m/n = 6/3 yields a much wider ergodized region up to $\rho > 0.75$ as shown in Fig. 4 (b), however, the averaged current decay time at m/n = 6/3 does not differ greatly from that at m/n = 6/1.

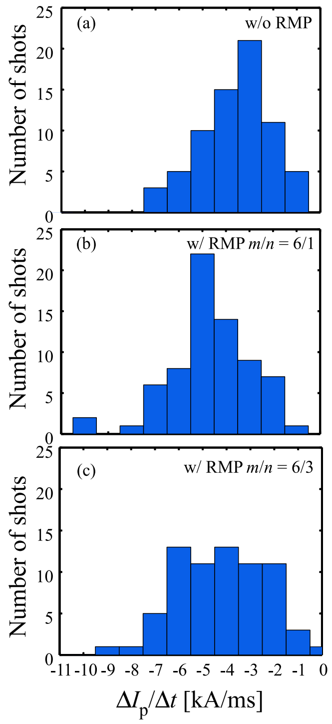

Fig. 3 Histogram of plasma current decay rate, $\Delta I_p/\Delta t$ (a) without RMP, (b) with RMP (n = 1), (c) with RMP (n = 3).

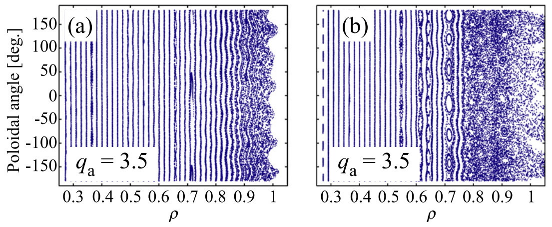

Fig. 4 Poincaré plots of magnetic line trace in poloidal cross section (a) with m/n = 6/1 RMP, (b) with m/n =6/3 RMP.

These experimental results indicate the application of RMP leads to faster current quench during disruption, which may enhance the electromagnetic force on the vacuum vessel. Therefore, the drawbacks should be considered in the next-generation tokamaks, in which ELMs will be mitigated by applying RMP.

In the future, we will investigate the physical mechanism for the rapid current decay induced by RMP by measuring the time evolution of the plasma current and the electron temperature profiles with a magnetic probe array or detached measuring method during the disruption.

[1] ITER Physics Basis, Nucl. Fusion **47**, chapter 3 (2003).
[2] T.E. Evans *et al*, Phys. Rev. Lett. **92**, 28 (2004).
[3] Y. Kikuchi *et al*, Nucl. Fusion **44**, S28 (2004).
[4] M. Okamoto *et al*, Nucl. Fusion **47**, 1106 (2007).