Observation of Minor Collapse of Current-Carrying Plasma in LHD

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A minor collapse observed in current-carrying plasma has been investigated in Large Helical Device (LHD). The magnetic configuration with high central rotational transform has $\iota/2\pi = 1$ surface at the core region and is relatively unstable for the $m/n = 1/1$ mode (here, m and n are the poloidal and toroidal mode number, respectively). When the beam-driven current exceeds a certain value, the $m/n = 1/1$ mode grows with a growth time of $\sim$ 30 ms and causes a sudden drop of the plasma stored energy and the electron temperature, and it also limits the plasma current itself. A local flattening in an electron temperature profile appears just after the minor collapse. The mode does not rotate and stays at the same spatial location. The possibility of pressure- and current-driven magneto-hydro dynamics (MHD) instabilities is discussed.

Keywords: Large Helical Device, MHD instability, plasma current

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In LHD experiment, we have obtained the β value (ratio of the plasma pressure to magnetic pressure) of over 4% without the disruptive phenomenon. The $m/n = 1/1$ mode (m and n are the poloidal and toroidal mode number, respectively) when its rational surface is located in the periphery is not crucial for high β plasma production, even when the linear growth rate of the ideal interchange mode has a finite value, and the relationship between the experimental results and the linear stability boundary of the mode has been discussed [1]. In general, the $m = 1$ mode leads to a large deviation of the magnetic axis when the resonance is located in the core region, which is likely to have a large impact on the plasma confinement compared with the mode excited in the periphery. In that case, the net plasma currents such as a beam-driven current and a bootstrap current not only violate the stability through the change of the magnetic shear, but also become the source of the so-called current-driven instability when the current exceeds a threshold [2]. Here, an effect of the net plasma current on the $m/n = 1/1$ MHD mode is reported, and the effect of the lowest-order resonant mode on plasma confinement is discussed.

Experiments were carried out in the configuration with a high central rotational transform of $\iota_0/2\pi = 0.58$ in order to decrease the magnetic shear around the $\iota/2\pi = 1$ surface. The time evolution of the discharge is shown in Fig. 1. Target plasma is produced and maintained by neutral beam injection (NBI), which drives the plasma current I_p in the co-direction. A Ne gas puff is applied at t = 1.1–1.2 s (Fig. 1(a)) to improve the power deposition and consequently increase the ramp-up rate of the I_p. After the Ne puff, the central beta value β_0 increases and approaches about 0.5 %. When the I_p/B_t (here, B_t is the toroidal magnetic field) reaches 39 kA/T at t ~2.06 s (Fig. 1(b)), the electron temperature T_e measured with an electron cyclotron emission (ECE) diagnostic suddenly drops (Fig. 1(c)), and the line-averaged electron density $\bar{n}_e$ increases (Fig. 1(d)) while the radial magnetic component of the $m/n = 1/1$ mode b_{r11}/B_t, which is estimated by magnetic flux measurement, increases (Fig. 1(e)). One reason for the increment of $\bar{n}_e$ may be that the neutral particle can enter the confinement region due to the decrease of T_e (shrinkage of the plasma). And that increment occurs after the drop of T_e and the increment of b_{r11}/B_t.

The minor collapse occurs twice during the discharge, but the plasma discharge is not terminated by this collapse. The toroidal angle of the X-point of the mode at the outboard side maintains a certain value during the discharge, as shown in Fig. 1(f), which means that the mode almost does not rotate. The extended view of the Fig. 1 discharge is shown in Fig. 2. Before the collapse at $t < 2.0$ s, the inverse of the characteristic time of the plasma stored energy

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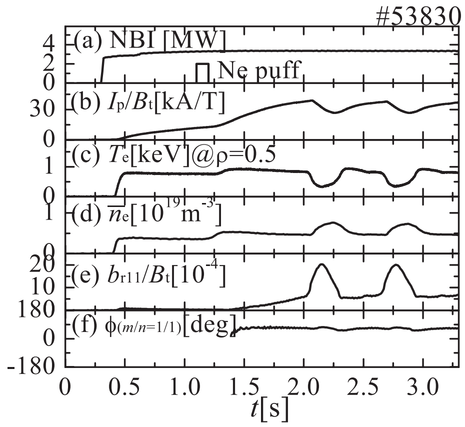

Fig. 1 Time evolution of (a) the port through power of NBI and neon puff, (b) plasma current I_p/B_t, (c) electron temperature T_e, (d) line-averaged electron density $\bar{n}_e$, (e) radial magnetic component of $m/n = 1/1$ mode b_{r11}/B_t, and (f) toroidal angle of X-point of $m/n = 1/1$ mode at outboard side $\phi_{(m/n=1/1)}$.

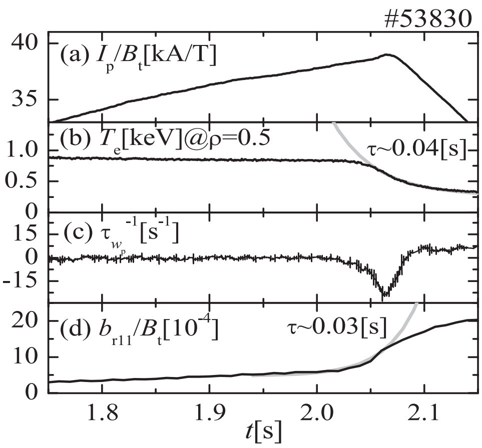

Fig. 2 Time evolution of (a) I_p/B_t, (b) T_e, (c) τ_{wp}^{-1} and (d) b_{r11}/B_t during minor collapse.

$\tau_{wp}^{-1}(= (dw_p/dt)/w_{p(t=2.0[s])})$ and the T_e are almost constant, while the I_p continues rising and the finite b_{r11}/B_t gradually increases. At $t = 2.06$ s, the decay time of w_p becomes ~40 ms and the growth time of b_{r11}/B_t is about 30 ms, which are longer than the growth time (the order of 100 μs) of the ideal MHD phenomenon. The magnetic fluctuation and the soft X-ray diagnostics do not show any precursors or post-cursors of the collapse. When the b_{r11}/B_t gradually develops until $t = 2.0$ s, the T_e profile measured with the Thomson system shows a slight flat region around $R = 3.38 \sim 3.55$ m and $4.12 \sim 4.24$ m (open circles in Fig. 3(b)). After the collapse, the b_{r11}/B_t increases faster than before the collapse and the width of the flat region expands toward the plasma center region, $R = 3.33 \sim 3.67$ m and $3.99 \sim 4.28$ m (closed circles in Fig. 3(b)). As a result, the central T_e decreases from 1.2 to 0.5 keV. The increase of the width of the flat region indicates the growth of the magnetic island with $m/n = 1/1$ structure by the

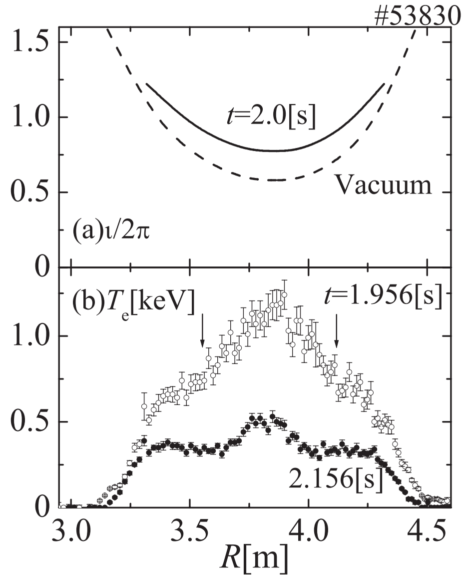

Fig. 3 Profiles of (a) rotational transform measured with MSE, and (b) T_e before and after minor collapse. The position of arrows corresponds to $\rho = 0.5$.

development of the perturbed magnetic field, which is observed by the magnetic diagnostics [3]. The position of the flat region corresponds to the $\iota/2\pi = 1$ resonant surface, as shown in Fig. 3(a), which is measured with motional Stark effect spectroscopy (MSE) diagnostics [4] in which the current density profile is parabolic.

According to the theoretical prediction calculated by using 3-D stability code, **TERPSICHORE** [5], an increment of the plasma current leads to the destabilization of the current-driven mode, and it forms a wide radial structure of the $m/n = 1/1$ Fourier mode in the core region. The observed mode causes large flattening of the T_e profile in the plasma core, as shown in Fig. 3(b), and it is qualitatively consistent with the results from **TERPSICORE**. The predicted threshold I_p/B_t for the destabilization of the ideal MHD mode is estimated as about 55 kA/T at the $\beta_0 = 0.5$ % (slightly larger than the experiments), in which the current-driven component is dominant. The difference between the experiment and the calculation is that the increment of the effective atomic number due to the Ne gas puff decreases the magnetic Reynolds number, which might increase the growth rate of a resistive mode [6].

A collapse was observed in the current-carrying plasma in Heliotron-E [7], and the collapse was explained by the appearance of the $m/n = 1/1$ internal kink mode at the $\iota/2\pi = 1$ resonant surface in the negative shear ($d\iota/d\rho < 0$) region of the rotational transform profile with the double resonant surfaces. In this experiment, the $\iota/2\pi$ profile is not a double resonant one. Therefore, it seems that a physical mechanism different from that described in Ref. [7] exists in this experiment.

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