21PA-013

Instability at the low-q operation in small tokamaks
小型トカマク装置における低q運転時の不安定性

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In tokamak plasma, external MHD mode control is important for improvement of plasma confinement, because the growth of MHD instability causes disruption, which yields the intense heat load, large electromagnetic force to the vacuum vessels. External kink instability is caused by the low plasma surface safety factor and the flat plasma current density profile, specifically the current gradient at the plasma surface is effective for instability. In this study, we have investigated the MHD instabilities when the plasma current density was changed in time in a small tokamak, HYBTOK-II, as a preparation experiment for MHD mode control by applying RMP.

1. Introduction

Recently, external perturbation field has been widely applied for various purposes in magnetic confinement systems. One of magnetohydrodynamics (MHD) instabilities leading to disruption of takamak devices is the resistive wall mode (RWM), which is an ideal external kink mode affected by a resistive wall. The effect of active feedback control coils and plasma-wall separation on the RWM stability was investigated in several toroidal devices [1, 2, 3]. On the other hand, in H-mode plasma, abrupt and repetitive heat load to the divertor plate is occurred by edge localized mode (ELM). It was reported that ELM is mitigated and suppressed by resonant magnetic perturbation (RMP) coils in DIII-D tokamak [4], and RMP coils is planning to be installed in ITER. Therefore, it is important to investigate the interaction between RMP fields and various MHD activities experimentally.

In the low-q discharge of small tokamak HYBTOK-II, we observed disruption occurred by the interaction between tearing mode and internal kink mode during ramp-up of plasma current [5]. In this study, we investigate characteristics of MHD instabilities when the ramp-up rate of plasma current is changed to identify the instabilities appeared in the HYBTOK-II.

2. Experimental set-up

We use small tokamak device HYBTOK-II which has limiter configuration. The major radius R is 40 cm, minor radius r is 12.8 cm, limiter radius a is 11 cm [6]. The discharge duration is 20 ms and working gas is hydrogen. In this device, it is possible to measure magnetic field of internal plasma by using magnetic probe array. This array consists of eight coils placed radially 5.5 mm intervals and inserts into the vacuum vessel from the bottom to measure poloidal magnetic field B_θ. During the discharge, top coil of the array is located at r = 5.5 cm from the plasma center.

3. Experimental result and Discussion

The typical waveform of plasma current I_p in ramp-up discharge is shown in Fig. 1. The ramp-up of I_p is driven by 5-13 kA in 1ms. In this discharge, the toroidal magnetic field strength B_T was ~0.3 T. As I_p ramps up, the plasma surface safety factor q_a decreases. From the poloidal magnetic field B_θ waveform in Fig. 1, it is found that B_θ at all positions is slightly decreased at about t = 13.6 ms and B_θ at r = 5.5cm is drastically decreased at about t = 14 ms. In addition, the positive spike of B_θ at the peripheral region is observed and the plasma column moves inward at t = 14 ms. It may indicate that MHD instability occurs at t = 13.6 ms and the minor collapse appears at t = 14 ms. Fig. 2 shows the peaking factor ν of plasma current density profile $j_\phi(r)$ during rump-up of I_p. The value of is evaluated by following equation:

$$j_\phi(r) = j_0\{1-(r/a)^2\}^\nu. \quad (1)$$

From Fig. 2, the current density profile becomes broader due to the skin effect in the initial phase of I_p ramp-up. The value of becomes minimum at t = 13.6 ms and continues to increase. Just before the minor collapse, ν= 1.1, q_a = 3.0. And the plasma current density profile becomes more peak after the minor collapse.

The safety factor q-profile just before t =13.6 ms and t = 14 ms is shown in Fig. 3. Each value of the q-profile is time-averaged over 0.05 ms. The rational surfaces of q = 3, 4 and q = 2, 3 are appeared just before t = 13.6 and 14 ms, respectively.

Fig. 4 shows the result of the stability analysis. Here, the mode m = 3, n = 1 is analyzed. The intensity in Fig. 4 indicates the growth rate of instabilities associated with kink mode and tearing mode. In Fig. 4, the closed circle, closed square and cross indicate the conditions at t = 13.55, 13.92 and 14.25 ms, respectively. It is found that m/n = 3/1 tearing mode at t = 13.55 ms is stable, the kink mode at t = 13.92 ms is stable and the kink mode at t = 14.25 ms is stable. In future, we investigate the stability of other MHD modes.

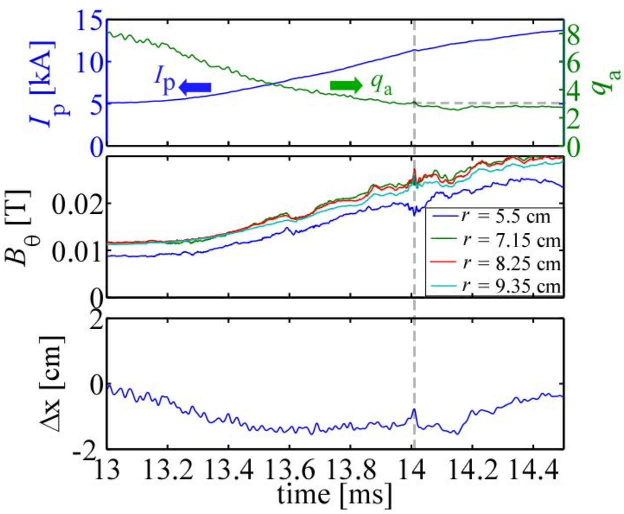

Fig. 1 Time evolution of (a) plasma current I_p, plasma surface safety factor q_a (b) poloidal magnetic field B_θ measured by magnetic probe array (c) horizontal position of the plasma column

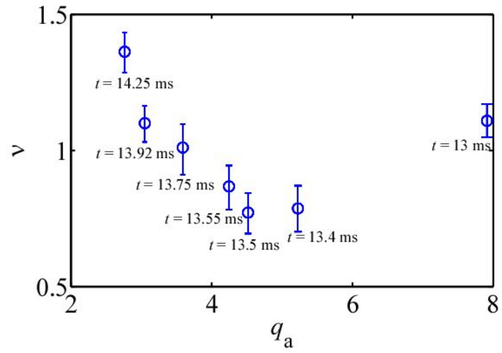

Fig. 2. Relation between the peaking factor ν of plasma current density profile and plasma surface safety factor q_a during rump-up of plasma current.

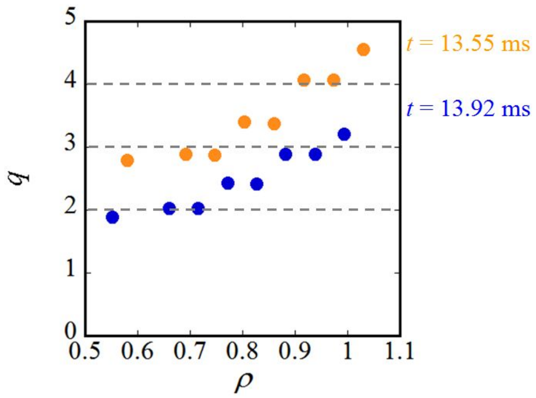

Fig. 3 q-profile just before the appearance of MHD instability and minor collapse.

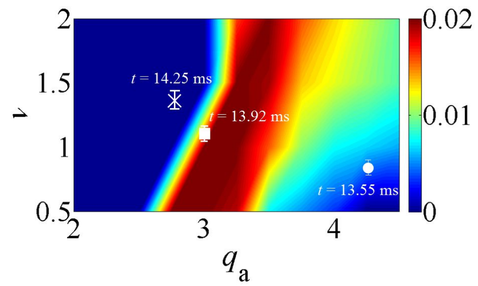

Fig. 4 Linear growth rate of m/n = 3/1 external kink and tearing mode. The point in the figure denotes the values just before the minor collapse.

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