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Experimental study of current driven MHD mode in LHD

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1.Introduction

Heliotrons do not require the plasma current for the magnetic field to confine plasmas. However, net toroidal currents can be generated by the Neutral Beam Injection (NBI) or bootstrap current and so on. These kinds of current play an important role from the viewpoint of Magneto-Hydro Dynamic (MHD) stability because the plasma current modifies the profile of the rotational transform $\iota/2\pi$, which affects the characteristics of the pressure and/or current driven MHD instabilities. Some experiments have reported the influence of the toroidal current on the pressure and/or current driven MHD modes [1-3]. Furthermore, Heliotrons have an advantage to be able to distinguish the pure effect of the plasma current on the confinement when a disruption occurs because the fluctuating magnetic field accompanied by the current driven mode is treated as a 1st-order magnetic field while the confinement field (vacuum field) can be considered as a zero-order field. In tokamaks, it is difficult to distinguish between them because the toroidal current simultaneously affects both of the equilibrium and instability. To study the characteristics of the current driven MHD instabilities in Heliotron plasmas, discharged with large net toroidal currents, driven by the two co-NBIs which make the rotational transform $\iota/2\pi$ higher, has been done in the Large Helical Device (LHD).

2. Behaviour of current carrying plasma

In recent LHD experiments with large net toroidal current and high rotational transform, we observe a plasma collapse. The time evolution of a discharge with a collapse is shown in Fig.1. The co-NBIs continue to drive the plasma current. When the plasma current reaches I_p=38[kA/T] (kinetic beta is β_0=0.5[%]), the electron temperature T_e decreases to half within 0.1[s] (from t=1.7 to 1.8[s]). The line averaged electron density $<n_e>$ doubles in 0.3[s] (from t=1.7 to 2.0[s]). The plasma discharge does not terminate in spite of the collapse, in which the collapse is defined by dw_p/dt becoming negative before the termination of the NBI heating. Here, w_p is a stored energy. The detailed waveforms during the collapse are shown in Fig.2 with the inverse of characteristic time τ_{wp}^{-1} and the magnetic fluctuation (db/dt). Here, db/dt is the time derivative of magnetic fluctuation and τ_{wp}^{-1} is defined as τ_{wp}^{-1}=(dw_p/dt)/$w_{p(\text{at just before the collapse})}$. Before the collapse ($t$<1.7[s]), w_p, T_e and $<n_e>$ are constant while the I_p continues rising. The T_e and w_p begin to decrease at t=1.7 [s] while the n_e does not change. About 0.05[s] later, the electron density starts increasing and the plasma current goes down. The db/dt does not show any remarkable fluctuation (precursor) before the collapse. Furthermore, precursors are not observed in the soft X-ray diagnostics. The electron temperature profile indicates a wide flat region around the collapse as shown in Fig.3. Before the collapse (t=1.656[s]), the profile shows a slight flat region (closed circles). A flat region appears at both sides during the collapse at t=1.756[s] (triangles). After that (t=1.856[s]), the width (Δ) of the flat region grows up to Δ/a_p=0.43 (Here, a_p is a minor radius in real coordinate.), which occupies the profile (open circles). As a result, the electron temperature in the core region falls to half while the T_e profile at the peripheral region keeps its gradient. The position of the flat region corresponds to the $\iota/2\pi$=1 resonant surface as shown in Fig3(a) calculated with **VMEC**[4]. From the magnetic diagnostics, it is thought that this phenomenon suggests the production of a magnetic island with m/n=1/1 mode structure without rotation. In case of the higher β, (β_0=1.3[%] #53795) the attainable current becomes lower as shown in Fig.4. In the experiment, the toroidal current is driven by the NBI. The decreasing of T_e at a collapse leads the

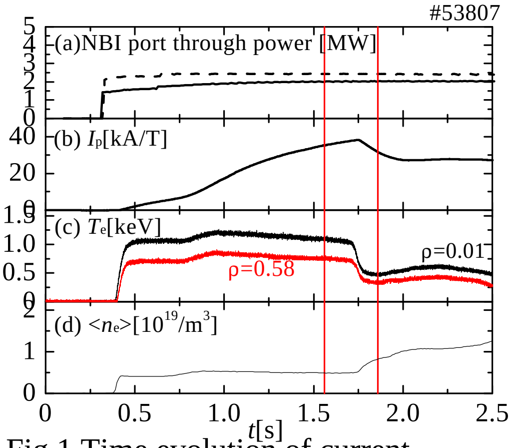

Fig.1 Time evolution of current carrying plasma. (a)Port through power of NBI (b)plasma current I_p (c)electron temperature T_e, (d)line averaged electron density $<n_e>$.

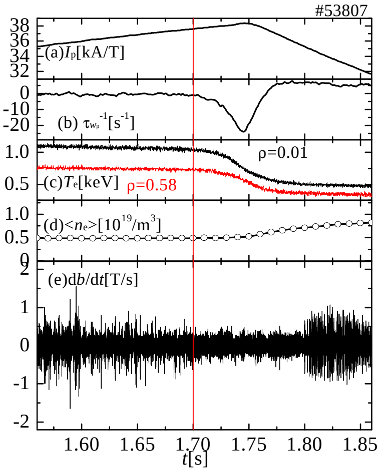

Fig.2 Time evolution of (a)I_p, (b)inverse of characteristic time of w_p (c)T_e, (d)$<n_e>$, (e)magnetic fluctuation around the collapse.

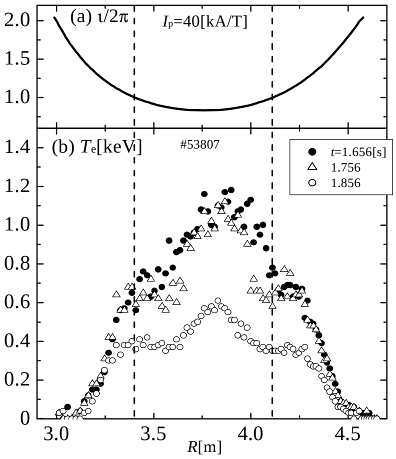

Fig.3 Profile of (a) $\iota/2\pi$ calculated with **VMEC** and (b) electron temperature.

drop of I_p via the reduction of the slowing down time therefore it is thought that there is a correlation between the attainable current and MHD instability. The MHD stability analysis with the low-*n* ideal 3-D MHD stability code **TERPSICHORE**[5] has been carried out to examine the characteristics of the current carrying plasma with finite β. For an equilibrium modelled, the profiles of the plasma current density and the pressure are assumed as $j(\rho)=j_0(1-\rho^2)$ and $\beta(\rho)=\beta_0(1-\rho^2)(1-\rho^8)$, respectively. Under these conditions, the unstable region of $m/n=1/1$ mode is shown in Fig.4 as a β vs. I_p space, which indicates that the plasma is destabilized in the high β and/or high I_p region. In case of the higher I_p region (I_p>40[kA/T]), the current driven term is dominant in the potential energy while the pressure gradient driven term is dominant in the case of lower I_p (I_p<40[kA/T]). There is a quantitative difference of the attainable current between the experimental results and theoretical predictions. One of the reasons is thought to be that the considerable beam pressure component contributes to an increase of the effective β. When the large toroidal current, the accuracy of the diamagnetic diagnostic becomes worse, which makes the measurement of w_p and β including the beam component difficult. For example, a calculation shows that the beam component amounts to 150[kJ], which rises the beta to β_0~1.5[%] from 0.5[%] in the plasma (#53807). The distribution of the potential energy of the plasma with β_0=1.5% and I_p=40[kA/T] shows that the current driven term is comparable to the pressure one in spite of relatively high beta.

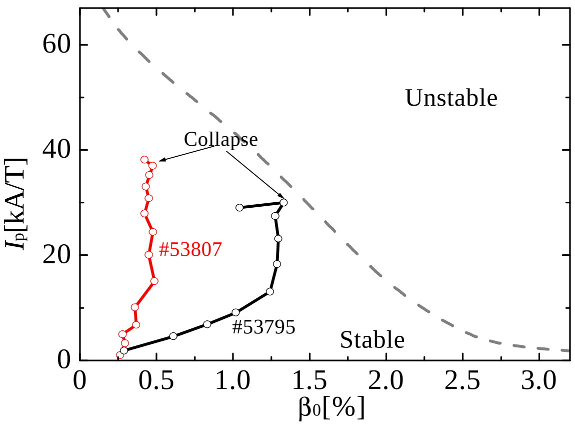

Fig.4 Trajectories of discharge in I_p vs. β_0 space. The $m/n=1/1$ mode is destabilized in the high β and/or high I_p region.

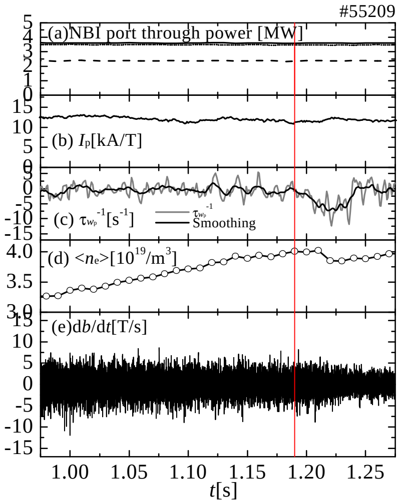

Fig.5 Time evolution of (a) Port through power of NBI, (b)I_p, (c) τ_{wp}^{-1}, (d)$\langle n_e\rangle$ and (e)magnetic fluctuation.

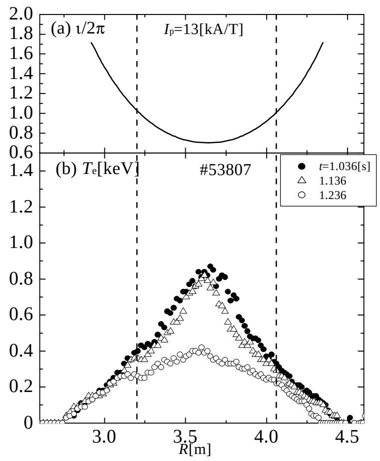

Fig.6 Profile of (a)$\iota/2\pi$ calculated with **VMEC** and (b)electron temperature.

3. Discussion

So far, the experimental results in LHD show that a pressure driven mode affects the energy confinement but does not lead to the collapse [6], therefore it can be thought that the collapse mentioned here indicates different features from that of the pressure driven mode. Recently, the collapses are observed in the configuration whose magnetic hill is extremely large. Figure 5 shows the time evolution of the high β plasma (β_0~3%). The toroidal current reaches I_p=13[kA/T] and the w_p degradation starts at t=1.19[s]. The magnetic fluctuation signal does not show any remarkable fluctuation and precursors leading to the collapse are not observed. The behaviour of the electron temperature profile shows the phenomenon to be similar to the case of low β–high I_p plasma as shown in Fig.6. These experimental results show the same behaviour between the low β - high I_p and high β - low I_p plasma, from the viewpoint that no precursor is observed and the temperature falls in the core region.

4.Summary

The current driven MHD mode has been studied in LHD plasmas. When the I_p reaches a certain value, the energy confinement degrades without any noticeable precursor. The electron temperature profile shows a large flat region, which leads to the modification of the profile mainly in the core region. The attainable current becomes lower with increasing beta, which is consistent with the prediction of the MHD stability analysis. However, there are quantitative differences of the attainable current between the experimental results and theoretical predictions. Taking into account the beam pressure, the MHD analysis shows that the m/n=1/1 mode is destabilized and the current driven term is comparable to the pressure one. A similar behaviour of the collapse is also observed in a configuration whose magnetic hill is extremely large. For further research of the current driven mode, it is necessary to produce a higher field plasma to reduce the beam pressure component.

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