Characteristics of MHD Instabilities Excited in Edge and Core Regions of the LHD Plasmas

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1. Introduction

The LHD experimental campaign in 1999 demonstrated that the plasma was fairly stable and did not suffer from serious plasma collapse caused by pressure driven modes such as ideal/resistive interchange modes and ballooning modes. The global plasma beta $<\beta_t>$ was increased more than 2 % [1]. Observations of magnetic fluctuations appeared to be consistent with the linear stability against Mercier modes and low n (n: toroidal mode number) interchange modes. These pressure driven modes saturated at a relatively low fluctuation level. However, in the experimental campaign in 2000 where high heating power was injected up to 6 MW, they sometimes exhibited peculiar nonlinear evolutions and appreciably affected the plasma confinement on a certain discharge condition . It is important to perform detailed studies of nonlinear behaviours of the pressure driven modes excited near the edge and core plasma regions, because their suppression and excitation are closely linked to local energy transport around the mode location. This paper reports the nonlinear behaviours of pressure driven modes observed in LHD plasmas and their effects on global plasma confinement.

2. Edge MHD modes with several satellites (Edge Harmonic Modes)

In the edge region of LHD plasmas where the steep pressure gradient zone is often generated, pressure driven modes accompanying several satellites are excited there[2, 3]. Mode structures depend on the toroidal plasma beta $<\beta_t>$ and the magnetic axis position. When one NBI pulse is occasionally turned off or the electron density is linearly increased up to relatively high value ($\approx$5-6 $\times 10^{19}$m^{-3}) by gas puffing, they rapidly grow and suddenly saturate within 1-2 ms, of which time scale is much shorter than the global energy confinement time and magnetic diffusion time. A typical discharge where the edge localized harmonic modes (EHM) are excited is shown in Fig.1. A typical frequency spectrum of magnetic fluctuations is shown in Fig.2. At least, 5th harmonics are clearly

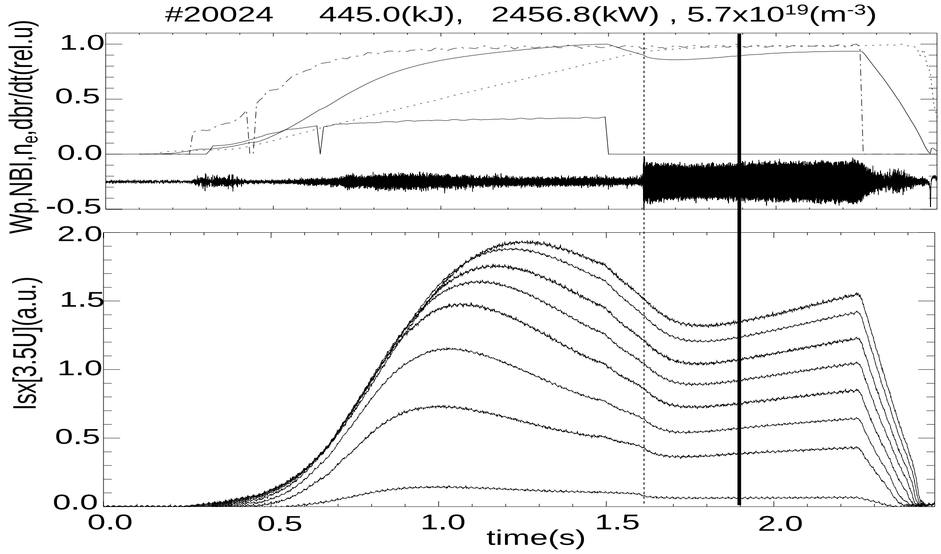

Fig.1 Discharge waveform with EHM-fluctuations where the total NBI heating power is ~3.2 MW. SX-signals from r/a~0.5 to ≈1 are shown.

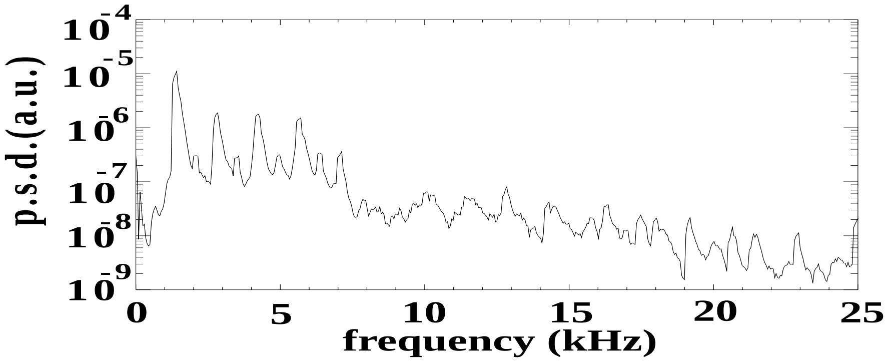

Fig.2 Frequency spectrum of magnetic fluctuations in the time window of 1.894~1.896 s.

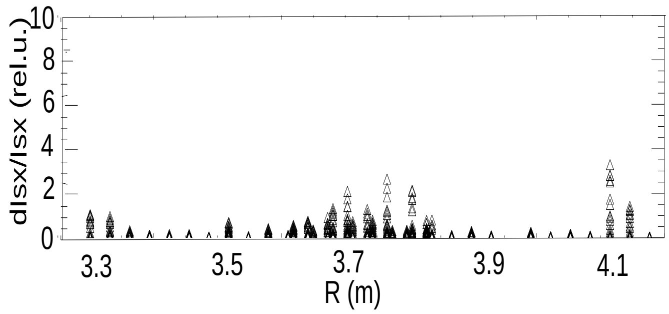

Fig.3 Relative amplitude of SX-fluctuations along the major radius.

seen in the frequency range less than 10 kHz. The toroidal (n) and poloidal (m) mode numbers for the fundamental mode with the lowest frequency ($f=f_o \approx 1.2$ kHz at t=1.89 s) are evaluated to be n=3 and m=2 using a magnetic probe array. Soft X-ray (SX-) detector array also detects the fluctuations and provides the information of m=2. Moreover, the SX- fluctuations are localized near the plasma edge (R > 4.1 m and R < 3.3 m) (Fig.3). According to VMEC calculation, the rational surface of the rotational transform 1/q=3/2 is located just outside the last closed flux surface(LCFS) , which means it is inside the ergodic layer. In the ergodic layer just outside LCFS, the pressure gradient seems to still be finite. The EHMs slightly but clearly decrease the plasma stored energy by ≈3 % (Fig.1). In the phase that EHMs persist, the other satellites having the frequencies of $f_o/2$, $3f_o/2$, $5f_o/2$ and so on are often excited(Fig.2). Note that these modes are very similar to the so-called edge harmonic oscillations(EHO) observed during so-called quiescent double barrier(QDB-) regime in DIII-D[4].

3. Edge harmonic modes with bursting character

As mentioned above, the edge harmonic modes EHMs are usually excited rapidly and persist continuously after quick saturation. In some cases with high heating power up to 6 MW where $<\beta_t>$ is only ≈0.6%, the EHMs exhibit bursting character and transiently depress the SX-signals from <r>/<a> ≈0.5 to ≈1 (Fig.4). It should be noted that the SX signals indicate the effect of the bursting EHMs reaches around half of the averaged minor radius <a>. The bursting EHMs appreciably decrease the stored energy Wp and transiently degrade the energy confinement time by up to 20% (Fig.5). The toroidal and poloidal mode numbers of the bursting EHMs at the lowest frequency (f≈6 kHz) are n=4 and m=3. Again, the rational surface is located very close to LCFS or just outside LCFS. When resonant helical field perturbations dominated by the m=1/n=1 Fourier component is externally applied using so-called Local Island Divertor (LID) coils so that an existing m=1/n=1 island should be suppressed, the bursting character of EHMs are

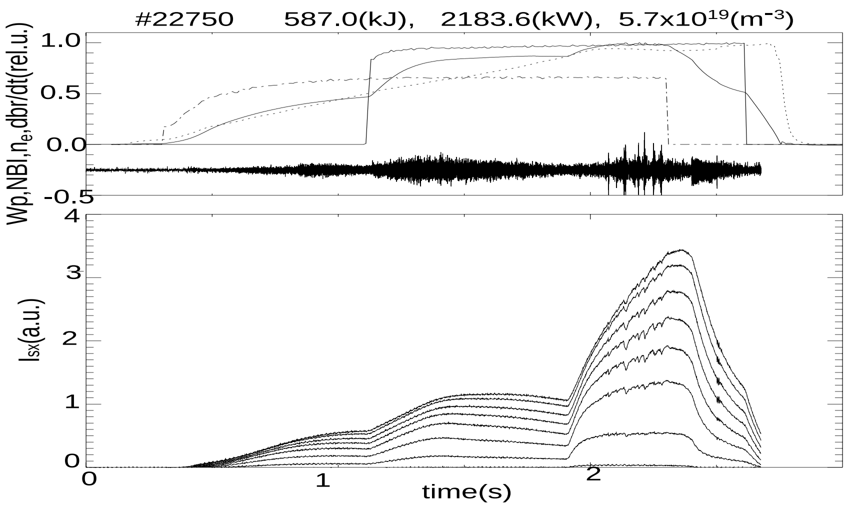

Fig.4 High power heating plasma with bursting EHMs, where ICRF power of 1.9 MW is injected in an NBI heated phase and total heating power is 5.6 MW. SX-signals from <r>/<a>≈0.5 to≈ 1 are shown.

clearly suppressed and Wp is smoothly increased(Fig.4). This might be caused by slight reduction in the pressure gradient near 1/q=3/2 surface through suppression of m=1/n=1 island. Also for the high temperature plasmas in the range of $<\beta_t> \approx 1\text{-}1.5$ %, the bursting modes sometimes affect the plasma confinement.

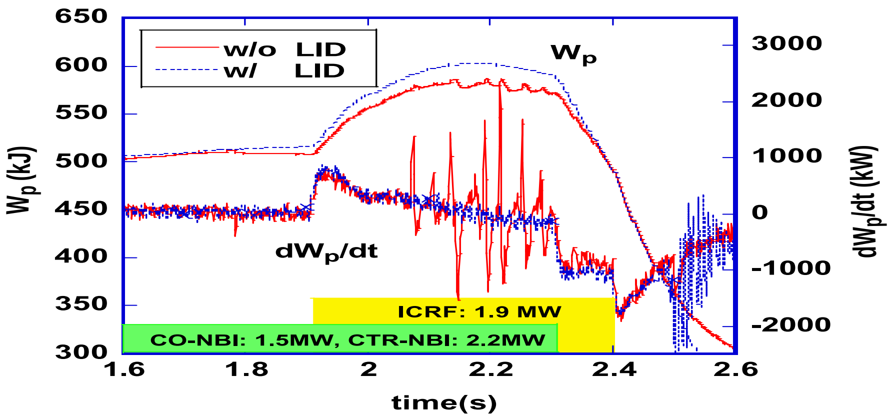

Fig.5 Time evolution of the stored energy and its time-derivative for two discharges without and with externally applied m=/n=1 resonant helical field perturbations.

4. MHD modes excited in the core region after ice pellet injection

After ice pellet injection, steep pressure gradient in the core region is transiently produced typically around the 1/q=1/2 rational surface. The magnetic shear at the rational surface tends to become small due to the increased in $<\beta_t>$. Indeed, m=2/n=1 pressure driven modes are often excited, inducing sawtooth like internal collapses. The effect of the internal collapse on plasma confinement is fairly small.

4. Summary

In LHD plasmas heated by a total power of about 6MW (NBI and ICRF), continuous and bursting MHD modes often having many satellites (in this paper, dubbed EHMs) are exited near the plasma edge. The bursting modes degrade the plasma confinement transiently but appreciably. The bursting character of EHMs with m=3/n=4 was successfully suppressed by resonant helical field perturbation when the field was applied to reduce the size of existing m=1/n=1 island. The continuous EHMs are sometimes rapidly destabilized and then quickly saturate, accompanying a lot of satellites. Just after the ice pellet injection, m=2/n=1 modes are often excited in the plasma core region and lead to internal collapse, of which effect on the plasma confinement is small.

Referrences

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