Pellet-Induced Low Frequency Oscillations on the Large Helical Device

S.Ohdachi, S.Yamamoto[1], K.Toi, A. Weller[2], R.Sakamoto, H.Yamada,
K.Tanaka, T.Tokuzawa, K.Kawahata, S.Morita, M.Goto, S.Sakakibara
and LHD Experimental Group

National Institute for Fusion Science, Toki 509–5292, Japan
[1]*Dep. of Energy Engineering Science, Nagoya Univ., Nagoya 464–8603, Japan*
[2]*Max-Planck-Institut für Plasmaphysik D-857p48 Garching, Germany*

1 Introduction

Hydrogen ice pellet injection has been successfully utilized for particle fueling of the Large Helical Device (LHD)[1]. With the help of sequential injection of pellets, typically five in sequence, we can reach an operational regime with fairly high electron density, in excess of $1 \times 10^{20}\mathrm{m}^{-3}$. The highest performance of the LHD plasma is achieved in this regime, where the density is being slowly decreased from its maximum value and the density profile is being transiently peaked. It is important to study the pellet-plasma interaction in order to optimize the ice pellet injection scheme.

Low frequency oscillations immediately following the pellet injection into NBI-heated plasma have been found on LHD. Those are similar to the Snake[2]-like oscillations found in tokamaks, e.g., ALCATOR C-mod[3], JET[2], RTP[4] and TEXTOR[5]. The characteristics of the oscillations in tokamaks are summarized as follows; (1) mode frequency is very low (several hundreds of Hz $\sim$ several kHz) with a poloidal mode number m = 1. (2) Oscillations appear in the SX radiations (SXR) and in the electron density fluctuations [2, 4, 5] and in the electron temperature fluctuations[5] using ECE measurement. (3) Oscillations are usually localized on the q = 1 rational surface. In RTP [4], formation of magnetic islands during ablation process has been found using Thomson scattering measurement with high space resolution. This observation supports the idea that oscillations are explained by the rotation of magnetic islands localized on the q = 1 magnetic surfaces. On the other hand, in the ALCATOR C-mod[3] tokamak, the peak of the oscillation are well outside the q = 1 surface. And m = 1 oscillations have been found in the Wendelstein 7-AS stellarator[6] where there is no q = 1 rational surface. Understanding of mechanism of this oscillations are in the still in the early stage. Here we present characteristics of pellet-induced low frequency oscillations found in LHD in detail.

2 Experiments

LHD is a Heriotron type device (l=2 / m=10) with the major radius R = 3.9 m and the minor radius $\overline{a}$ = 0.6 m. Pneumatic pipe-gun type injector is used to refuel the LHD plasma. Hydrogen ice pellets with a velocity of $\sim$ 1 km/s (from outboard side) and $\sim$ 0.2 km/s (from inboard side) can be injected with this.

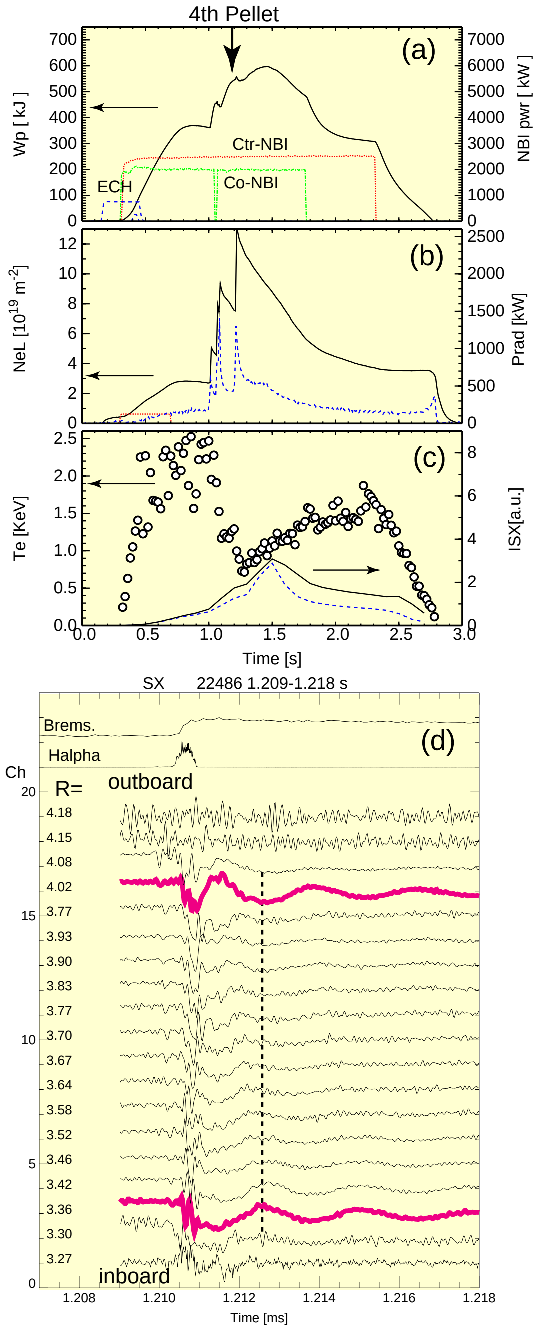

Fig.1: Time evolutions of the stored energy (a), the line density and the radiated power(b), the electron temperature T_{e0} and SXR at the center and the edge (c) are shown together. Fourth pellet(indicated by an arrow) make the oscillation at about 1.21 s. Extended view of H$_\alpha$ and SXR are shown in (d).

Time evolution of plasma parameters is shown in Fig.1(a)–(c) when oscillations are observed. Expanded view of signals from a soft X-ray (SX) detector array system[7] which views the plasma at a vertically elongated section of LHD is shown in Fig.1(d). Fast H$_\alpha$ measurement and the visible bremsstrahlung measurement are also shown to compare the timing of the pellet injection. After the ablation phase indicated by H$_\alpha$ peak, slow ($f \sim 400$ Hz) and dumping oscillation can be seen. Comparing the phase between inboard sight-line with outboard one (broad lines in Fig.1(d)), we find that poloidal mode number m = 1. Measurements at a different toroidal position, where the plasma is horizontally elongated, also show that m = 1 structure. Phase difference between two arrays is consistent with toroidal mode number n = 1, though measurements at only two toroidal positions are not conclusive. The oscillations persist for about 10 ms typically.

The fluctuation amplitude and the relative phase of the oscillations as a function of major radius R are shown in Fig. 2. Two peaks in the amplitude (Fig.2(a)) are located slightly inside the 1/q = 1 surface ($\rho = 0.7 \sim 0.9$). The position is independent of the conditions of pellets, e.g., size or speed or penetration depth of them. However, in the low magnetic field experiments (B$_t$ = 0.75 T, dashed lines in Fig. 2), where the magnetic surfaces are shifted outboard by Shafranov Shift in high beta plasma, inner peak also moves outboard. The disagreement with the position of q = 1 surface is larger than that in the low beta (B$_t$ = 2.8T) case. Estimation of the rotational transform profile and the averaged radius ρ are shown in Fig.2(a) and its axes above. This movement can be explained better by deeper penetration of pellets with low temperature plasma in high beta experiments than by movement of the q = 1 rational surface. It is possible the oscillation is not localized on the q = 1 surface in LHD.

3 Discussion

3.1 Density fluctuations or Temperature fluctuations?

While the pellet is being ablated, modulation of the H_α radiation, which suggests inhomogeneous ablation, are also observed (Fig.1(d)).

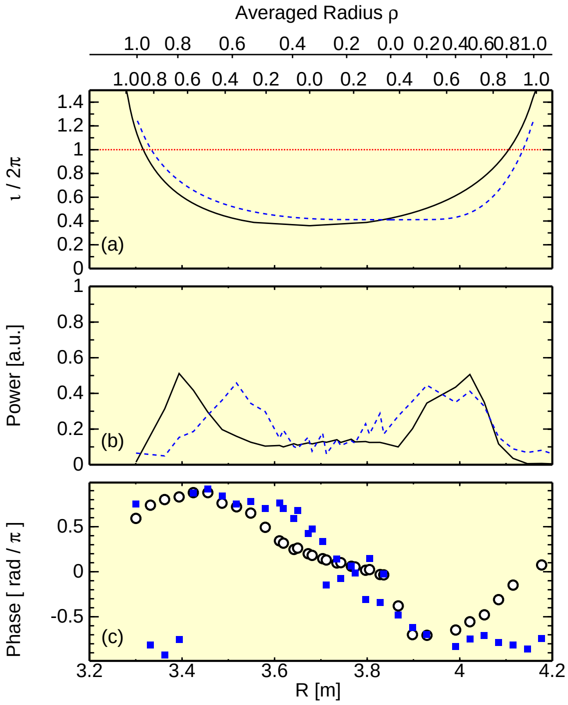

Fig.2: Rotational Transform $\iota/2\pi$ (a), the fluctuation amplitude (b)and the relative phase (c) as a function of major Radius are shown. Solid line (open circles) and dashed line (closed square) are high beta (β_t = 0.5%, #22486) and low beta (β_t = 1.4%, #23154) case, respectively. Estimation of the averaged radii assuming standard pressure profile are also shown in (a) for reference.

Simultaneously, faster fluctuations ($\sim$ 10 kHz) propagate or rotate from the outboard side to the inboard side are also observed. Since this modulations are correlated well with the density fluctuations measured by FIR interferometer, these can be explained by density fluctuations. However, slower waves, we are discussing, whose amplitude is as large as the fast oscillations, are not detected neither by the density measurement nor by the visible Bremsstrahlung measurement(Fig.1(d)). The SXRs depend on the electron density and temperature and the impurity density. Because fluctuations in the density and the impurity radiation are not large enough to account for the SXR fluctuations, the fluctuations are may be caused by the fluctuations in the electron temperature. However, We can not make a conclusive answer for this, because ECE measurements after the sequentially injected pellets are not available due to cutoff. Therefore, filter absorption method has been tested using two SX arrays equipped with beryllium foil of different thickness. Relative fluctuation levels are 25% and 20% with 15μm foil and 30 μm foil, respectively. It is not consistent with the idea – the electron temperature fluctuations cause the SXR fluctuations – since channels with thicker foil are more sensitive to the electron temperature. The origin of the SXR oscillations has not been understood yet.

3.2 When do the oscillations appear?

These oscillations are not always observed with pellet injections. We have found about 40 cases from 320 pellet injected discharges we checked. The criterion for their appearance will be key to understanding of this phenomena, however, no clear conditions, e.g. the size or the speed of pellets, the conditions of target plasma and so on, has been found. And this oscillations can be seen both in the hydrogen and the helium target plasmas.

In tokamak case, the appearance of the oscillations can be related to the pellets penetrating length and the position of the q = 1 rational surfaces. It is not the case with the LHD. Because the rotational transform profile of LHD is different from tokamaks; q = 1 surface is located in the relatively outer region (Fig.2 (a)). Thereby, almost every pellet can reach there including pellet injected from inboard side whose velocity is low (~ 200 m/s) due to the curved guiding tube. This slow pellet also make the oscillations sometimes.

3.3 Parameter dependence

Characteristics of the oscillations, i.e. the frequency, the decaying rate, etc. are compared with the experimental conditions. Unfortunately, no clear correlation has been found again; the frequency of the oscillations does not depend on B_t and depends weakly on the line averaged target plasma density (Shown in Fig. 3).

In summary, pellet induced sawtooth oscillations has been found in LHD. The frequency range, m/n = 1/1 mode structure is similar to Snakes found in tokamaks. Radial profile of amplitude of the mode suggests that they are not localized on q = 1 surface. The physical mechanism behind the oscillations has not been well understood. Further investigations are needed.

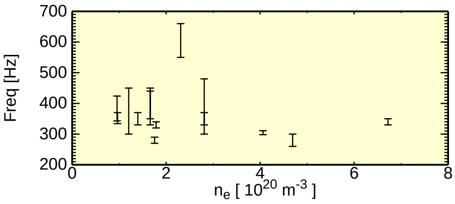

Fig.3: The frequency of the oscillations as a function of line averaged electron density. Error bars indicate the change of the frequency while decaying.

References

[1] R. Sakamoto *et al.*, Nucl. Fusion **41**, 381 (2001).

[2] A. Weller *et al.*, Phys. Rev. Lett. **59**, 2303 (1987).

[3] J. Parker *et al.*, Nucl. Fusion **27**, 853 (1987).

[4] D. Cruz *et al.*, Phys. Rev. Lett. **75**, 3685 (1995).

[5] K. Finken *et al.*, Plasma Phys. Control. Fusion **39**, 351 (1997).

[6] J. Lyon *et al.*, Proc. of 24th European Physical Society Conference on Controlled Fusion and Plasma Physics **21**, 1629 (1997).

[7] S. Ohdachi, K. Toi, M. Takechi, and S. Yamamoto, Rev. Sci. Instrum. **72**, 727 (2001).