Study of Edge Localized Mode in HL-2A Tokamak Experiments

Y. Huang, L. Nie, D. L. Yu, C. H. Liu, J. Cheng, X. Q. Ji, Z. Feng, Q.W. Yang, L.W. Yan
X.M. Song, Yi Liu, X.T. Ding, J.Q. Dong, X.R. Duan and HL-2A team
Southwestern Institute of Physics, P O Box 432, Chengdu 610041, China

E-mail contact of the main author: yhuang@swip.ac.cn

Abstract: The first observation of ELMy H-mode confinement has been made in divertor discharges with ECRH and NBI in HL-2A tokamak. This article present the results of HL-2A experiments aimed at studying the characteristic of edge localized modes(ELMs). And then, we try to use the unstable periodic orbits(UPOs) to search for deterministic chaos in ELM time-series.

1. Introduction

H-mode operation is extremely important and has been chosen as the standard operating scenario for ITER to meet its objectives, but ELMs expelled energy could cause surface damage to the first wall and , especially, to the divertor plates. For this reason, much effort has been spent worldwide on the understanding, mitigation and control of the ELMs, in order to avoid the largest and most destructive ELMs, while at the same time some level of particle and pressure control is maintained. In ASDEX, only type-III ELMs exist[1], and the energy loss caused by an ELM was of the order of 5%. In HL-2A, the preliminary results show that Type I and Type III ELMs were observed in the experiment, further study on the dependence of ELM frequency on heating power is in progress in future experiments.

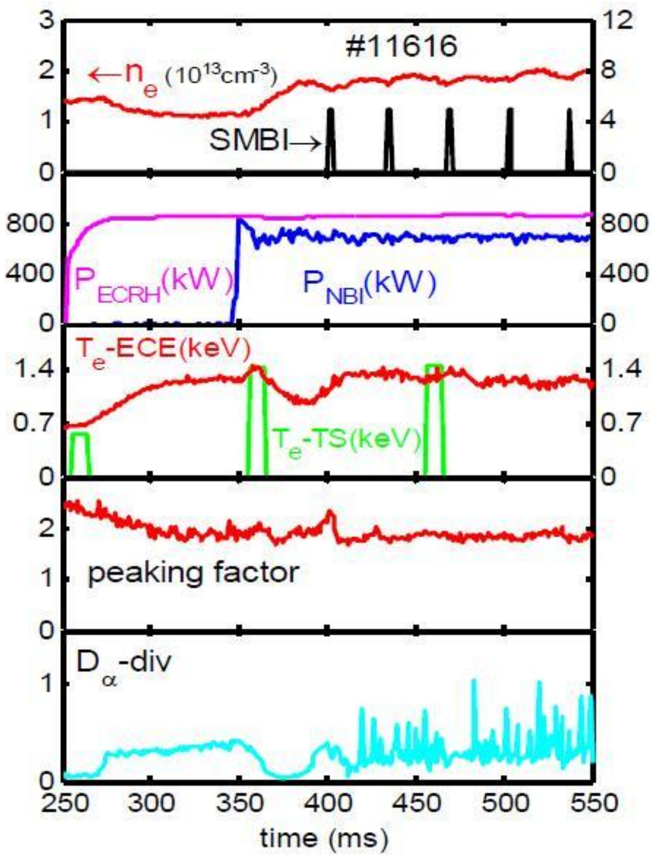

FIG.1. A typical discharge of H-mode with Type-III ELMs in HL-2A.

2. Type-I and Type-III ELMs

In HL-2A tokamak, the ELMy H-mode operation was first achieved [2] in 2009 experiment campaign, by combining the auxiliary heating of NBI and ECRH. The ELMs were detected by distinctive spikes in the Dα radiation from divertor chamber. An example of shot 11616 plasma parameters are given in Figure 1. From top to bottom are electron density, control signal for SMBI valve, ECRH waveform with 870 kW power from 260 ~ 900 ms, NBI waveform with 690 kW power from 300 ~ 890 ms, central electron temperature Te_e measured by Thomson scattering diagnostic and ECE radiometer, density peaking factor, Dα radiation from divertor. The H-mode phase is from 400 ~ 910 ms, which is ended with a time delay of ~10 ms after the auxiliary power is turned off.

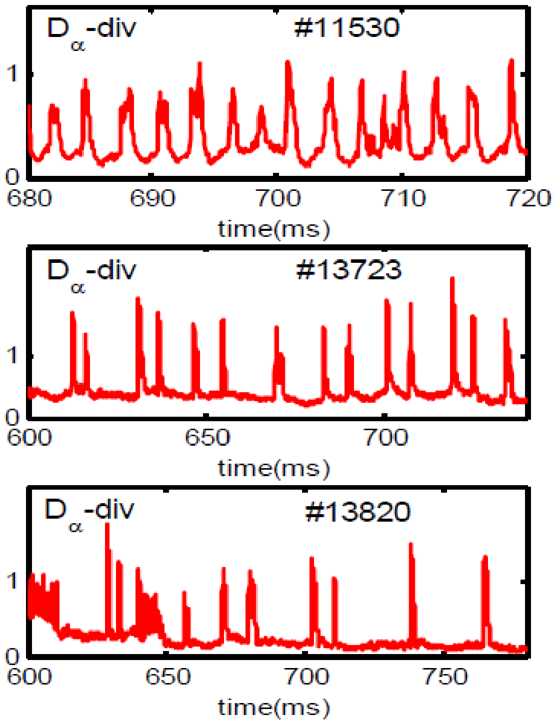

FIG.2. Time intervals for different ELMs

As shown in Fig.1, after L-H transition, the central-chord-averaged electron density increases and the density peaking factor decreases, indicating that the pedestal density increases. The core electron temperature almost keeps unchanged, so the pedestal electron temperature may changes a little. With the method to categorize ELMs by comparing the pedestal temperatures and densities of discharges [3], the ELM of present HL-2A H-mode operation may be recognized as Type III, with typical frequency about 400~600 Hz. As a first H-mode operation on HL-2A, the available data are not enough to confirm the conclusion. Further study on the

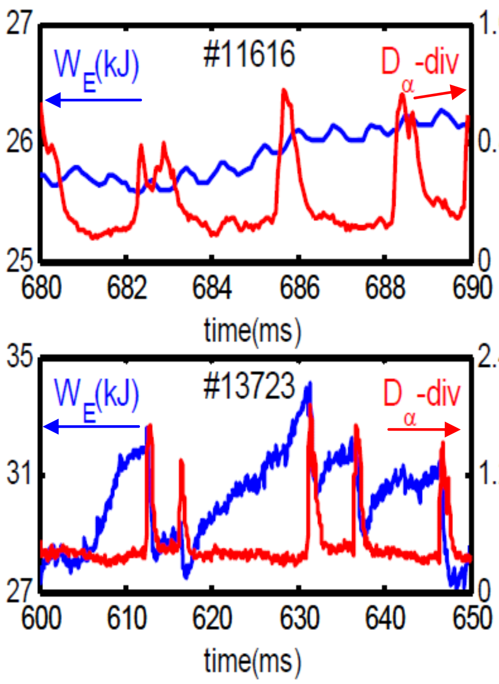

FIG.3, energy loss for an ELM

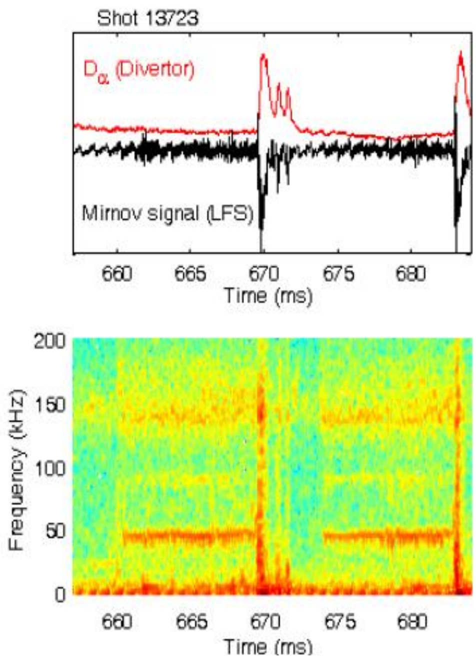

FIG.4. Magnetic fluctuations during an ELM

dependence of ELM frequency on heating power is in progress in present experiment campaign. The preliminary results show that Type I and Type III ELMs were observed in the experiment.

In 2010 Spring campaign, new features of ELMs were observed. As shown in Fig.2, two periods of ELMs were observed in shot13723, the time interval was longer than 10 ms and even more than 30 ms in shot13820.

Fig.3 presents the energy loss by an ELM. For a typical type-III ELM as in shot11616, the energy change is less by 3%; the ELM loss is more than 10% in shot13723, indicating the signature of a typical Type I ELM[4]. The ELM manifests itself on the magnetic fluctuation signal as a broadband turbulent phenomenon with frequencies reaching up to 180 kHz. Figure 4 shows a contour plot of the temporal evolution of the frequency spectrum of the magnetic fluctuations for a Type-I like ELM. The precursor is seen as a narrow line at about 50 kHz. Contrary to the experimental results in ASDEX, any magnetic precursor is hardly observed for a typical Type-III ELM. These preliminary results show that Type I and Type-III ELMs were observed in the experiment, further study on the dependence of ELM frequency on heating power is in progress in future experiments.

3. ELM magnetic precursors

Clear precursor modes associated with the type-III ELMs crash exhibiting a mode frequency f~45kHz are always observed by Mirnov probes on HL-2A. The ELM precursors start to grow about several hundred microseconds to several milliseconds before the onset of ELMs. The modes propagate in the direction of the electron diamagnetic drift. An example for the precursor modes, shot 14011 is shown in Fig.5. Fig.5(a) illustrates the spectrogram of Mirnov probe located in the outboard midplane (LFS). Prior to the ELMs which indicated by the rise of divertor D_α shown in Fig.5(c), clear precursor oscillation can be observed. The ELM precursors with f~45kHz, start to grow about 1 millisecond before the onset of ELMs. The precursors are also observed by the edge channel of soft X ray shown in Fig.5(b).

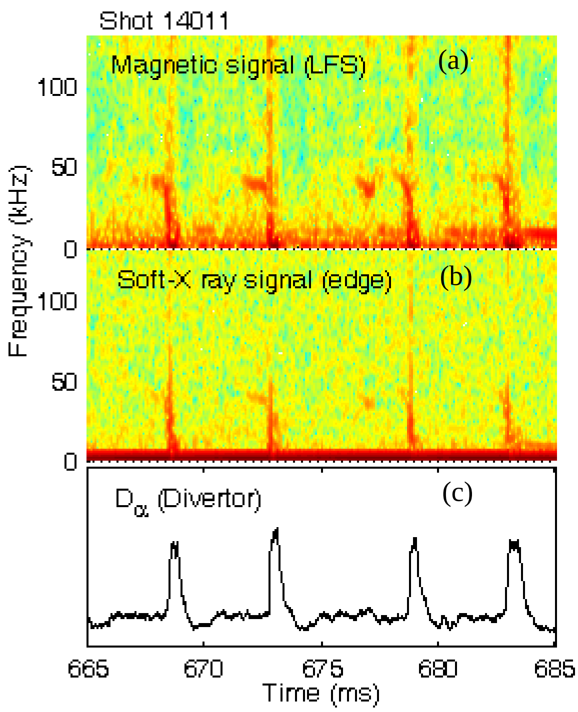

FIG.5. The Spectrogram of the ELM precursors from magnetic probe (LFS) and soft-X ray (edge channel). The divertor D_α indicates the onset of ELM.

Fig.6(a) and Fig.6(b) show the raw signals of Mirnov probes located on the low field side and high field side, respectively. The ELM precursor is only detected on the LFS probe shown in Fig.6(b). However, the distances of the two coils to the separatrix on the low and high field sides is comparable(~10cm). This initially suggested that the precursors have strong ballooning character, which is stabilizing on the inner side of the torus and destabilizing on the outer side. Before ELMs onset, the amplitudes of the precursor always grow with a typical growth time of several hundred microseconds, and at the same time the frequency decreases. As shown in Fig.6(b), sharply growth of the precursor amplitude with a growth time 0.2 milliseconds and decrease of the frequency from 45kHz to 30kHz before D_α rise can be observed by the LFS probe.

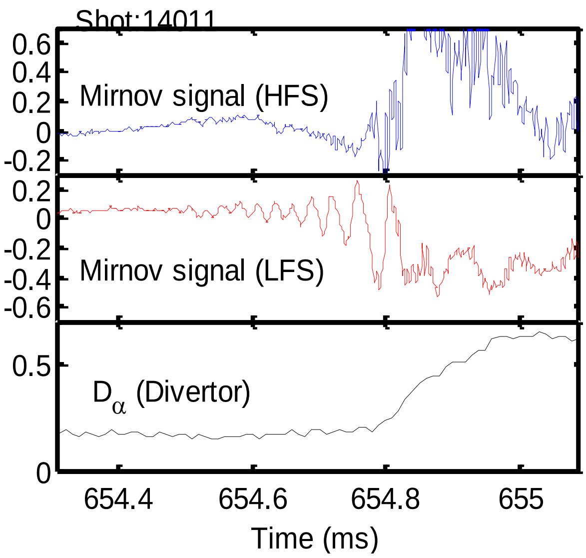

FIG.6. Strong poloidal asymmetry of the precursor is observed by the LFS and HFS Mirnov probes. And the amplitude of the precursor grows rapidly before the ELM crash

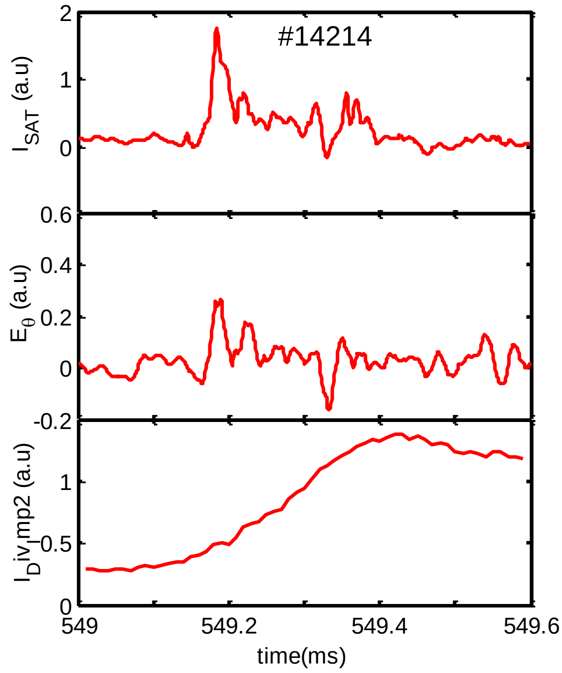

FIG.7. Ion saturation current I_{STA} and poloidal electric field E_θ in a filament

4. Radial velocity of filament

The ELM plasma released from the pedestal is evolved into filamentary structure in SOL region. During a single ELM, the ion saturation current (I_{STA}) of the mid-plane blob Langmuir probe, as well as the signal of Mirnov coil, has many peaks. Each individual peak is considered as a single filament. Radial velocity of filaments are calculated from time delay between the maximum of the I_{STA} and floating voltage V_f measured by the a three-tip probe array. Fig.7 show the signals of Langmuir pins near the last closed flux surface (LCFS), $B_t = 1.31\mathrm{T}$. I_{STA} is the ion saturation current and E_θ is the poloidal electric field which is measured by the floating voltage V_{f+} and V_{f-}. Use the signals I_{STA} to find the filamentary, and then, with $V_r = E_\theta / B_t$ can obtain the radial velocity V_r which is about

1.2km/s. However, this result is an estimation, If we want to acquire the effective radial velocity, we must use a large number of filaments signal to analyse.[5]

5. Chaotic feature of the observed ELMs:

The chaotic feature of the observed ELMs is analyzed with unstable periodic orbits (UPOs) [6]. The ELM events exhibit irregular behavior, in contrast to that ELM time series which show regular periodic behavior because ELM process is governed by the reduced transport during the H-mode and the threshold condition for MHD instability.

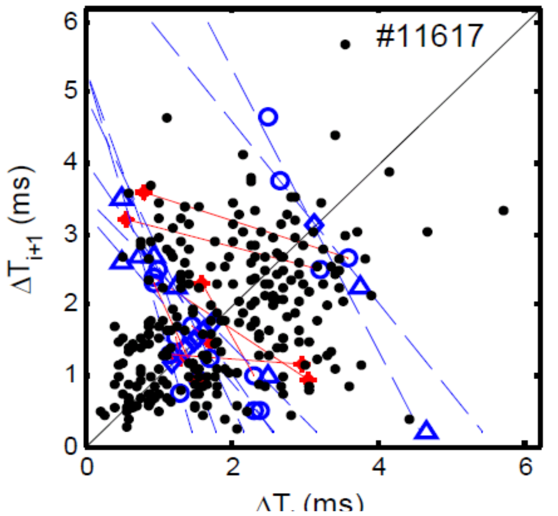

FIG.8, The first return map of the inter-ELM periods ΔT_i versus ΔT_{i+1} for shot11617

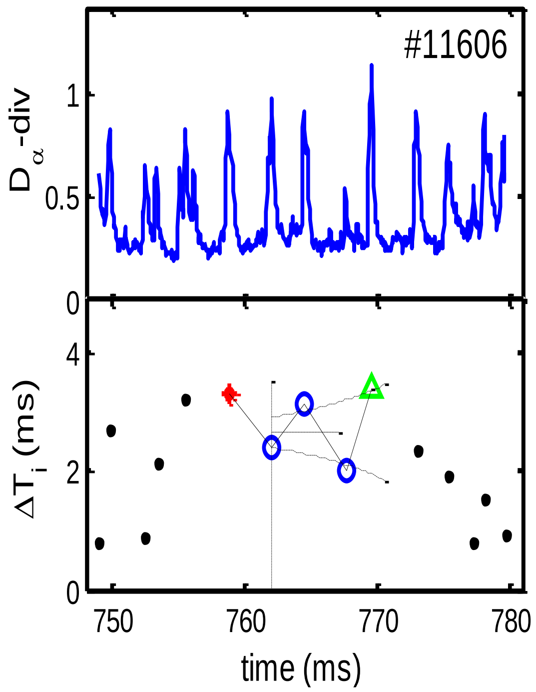

FIG.9, top plot is the Dα signal of the ELMs and the bottom is a UPO candidate.

If the ELM with amplitude A_i occurs at the time t_i, then the ELM interval Δt is defined by the time variance from this ELM to the next ELM: $\Delta T_i = t_{i+1} - t_i$. It is shown obviously that ELM events exhibit irregular behavior. There are two extreme considerations about the reason why such irregular behavior can arise: the system is random, or the system is in a chaotic state. The chaotic feature of the observed ELMs is analyzed with unstable periodic orbits (UPOs) [7]. The recurrence method [8] detects chaos in discrete time series by searching for UPOs. The method simply fits some consecutive points to a straight line on the first return map and if the absolute value of the linear regression coefficient is more than 0.98, a UPO is found. The specific criteria are: (i) Departure phase: The occurrence of at least three consecutive collinear points $((\Delta T_i, \Delta T_{i+1}), (\Delta T_{i+1}, \Delta T_{i+2}), (\Delta T_{i+2}, \Delta T_{i+3}))$with linear regression coefficient > 0.98 and a slope s_+ < -1. The location of the fixed point ΔT^* is obtained as the intersection point of the best fitted line from these points with the diagonal. (ii) Approach phase: The slope of the line connecting the fixed point $(\Delta T^*, \Delta T^*)$ with the point $(\Delta T_{i-1}, \Delta T_i)$

has a slope s_{-1} between 0 and -1. The point ($\Delta T_{i-1}, \Delta T_i$) also is on the other side of the diagonal to the point ($\Delta T_i, \Delta T_{i+1}$).On the first return map, the transient approach and departure phases of a UPO appear as sets of consecutive points that follow straight lines, as shown in Fig. 8. An UPO is shown obviously from the signal of I-Div-Dα in Fig.9. The asterisk denotes the beginning of the approach phase, the triangle denots the end of the departure phase. The position of the fixed point is denoted by the horizontal dashed line, and the exponential departure phase is shown by the curved dashed lines. The vertical dashed line denotes the point of closest approach. The UPOs in the ELM time series have been observed, indicating that a deterministic, chaotic process of ELMs in HL-2A tokamak. For a chaotic system, UPOs can be stabilized with small perturbations of available control parameters, thus it is a possible technique to mitigate ELMs by controlling UPOs, thereby increasing the ELM frequency and consequently decreasing the ELM energy loss.

Summary

The preliminary results in 2009 and 2010 campaign of HL-2A , we obtain the H-mond and observe type Ⅲ ELMs like the currentshot 11616 which the energy change is less by 3% and the currentshout 14011 whit magnetic precursors about f~45kHz, and we find the currentshot 13723 has some characteristic of type I ELM , the energy loss is more than 10% . then we try to use UPOs to analyse the ELM，search for deterministic chaos in ELM time-series and may be used to control the ELM events.

References:

[1] H. Zohm, et al., Nucl. Fusion 32 (1992) 489
[2] X. R. Duan, et al., Nucl. Fusion 50 (2010) 095011
[3] H. Wilson, Transactions of Fusion Science and Technology 53 (2008) 161
[4] H. Zohm, et al., Nucl. Fusion 35 (1995)543
[5] J. Cheng ,et al, Plasma Phys. Control. Fusion 52 (2010) 055003
[6] A.W. Degeling, et al., Plasma Phys. Control. Fusion 43 (2001) 1671
[7] P. E. Bak, et al., Phys. Rev. Lett. 83(1999) 1339
[8] A.W. Degeling, et al., Plasma Phys. Control. Fusion 43 (2001) 1671