The features of (2,1) NTMs on EAST tokamak

T.H. Shi,[1, a)] B.N. Wan,[1] B. Shen,[1] Y.W. Sun,[1] J.P. Qian,[1] L.Q. Hu,[1] Y. Chen,[1] C.Z. Li,[1] L.Q. Xu,[1] and EAST Team[1]

Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, Peoples Republic of China

Neoclassical tearing mode(NTM) has been observed in discharges with auxiliary heating LH+ICRF and LH only during H-mode in EAST tokamak, respectively. $m/n = 2/1$ NTM triggered by strongly coupling with an $m/n = 1/1$ internal mode is the most common phenomena at the moment on EAST tokamak. The spontaneous like triggering $(2, 1)$ NTM, ELMs triggering $(2, 1)$ NTM and sawtooth crash triggering $(2, 1)$ NTM are also observed in 2012 experiment on EAST tokamak. From statistical results, the $\beta_{N,onset}$ and magnetic island critical width w_{crit} increase as electron temperature T_e. And the $(2, 1)$ NTM can be excited easily at $q_{95} < 4.3$.

(Some figures in this article are in colour only in the electronic version)

I. INTRODUCTION

Neoclassical tearing mode(NTM) is one of the most concerned MHD instabilities in ITER discharges[1]. It is destabilized and maintained by helical perturbations to the pressure-gradient driven bootstrap current. NTMs degrade both plasma energy and angular momentum and lead to disruption in a high β palasma, bringing great damages to device. NTMs have been observed in most of tokamaks, since NTMs were first observed in TFTR.

Recently, in EAST tokamak[2], $(2, 1)$ NTM triggered by mode coupling with $(1, 1)$ internal mode has been reported[3]. That is the most common events at the moment in 2011 and 2012 experiments on EAST tokamak. The sawtooth crash, ELMs and spontaneous triggering $(2, 1)$ NTM are also observed in EAST tokamak, which are shown in this paper.

This paper is organized as follows. The features of NTMs are shown in section 2. In section 3, the phenomenon, $(2, 1)$ NTM is suppressed by pellet injection, is shown. The statistical results are shown in section 4. In final section, main conclusions are presented.

a) thshi@ipp.ac.cn

II. THE FEATURES OF $(2, 1)$ NTMS ON EAST TOKAMAK

A. Experiment setup

In EAST tokamak, high confinement plasmas(H-mode) have been achieved with auxiliary heating LH+ICRF and LH only[4], respectively. NTMs are observed during H-mode phase with $I_p > 400$ kA, $B_T = 1.75-1.95$ T, $q_{95} = 3.0-4.8$, Line-averaged electron density $\bar{n}_e = (2.5-4.5)\times 10^{19}$ m^{-3} at $R = 1820$ mm, ion temperature $T_i \approx 1.0$ kev, the elongation $1.63 < \kappa < 1.90$, the lower triangularity $0.4 < \delta_d < 0.53$, the upper triangularity $0.2 < \delta_u < 0.53$ and most plasma shapes are LSN(Lower Singal Null) and DN(Double Null).

B. (2,1) NTM triggered by mode coupling with (1,1) internal mode

The phenomena, $(2, 1)$ NTM is excited by mode coupling with $(1, 1)$ internal mode[3], are the most common events in 2011 and 2012 experiments on EAST tokamak.

The main characteristics are shown in Fig.1. The $(2, 1)$ NTM appears during H-mode. The big $(1, 1)$ internal mode provides a seed island for $(2, 1)$ NTM through strong mode coupling. In shot 38206, the auxiliary heating power: $P_{ICRF} = 1.0MW$ and $P_{LH} = 1.3MW$. The saturated island width w_{stu} changes as the β_p changing as shown in Fig.1(d). There is an obvious seed island as shown in Fig.1(g,h). The frequency $f_{1/1}$ of $(1, 1)$ internal mode is same with $f_{2/1}$ of $(2/1)$ NTM as shown in Fig.1(e,f). The $(1, 1)$ internal mode is characterized

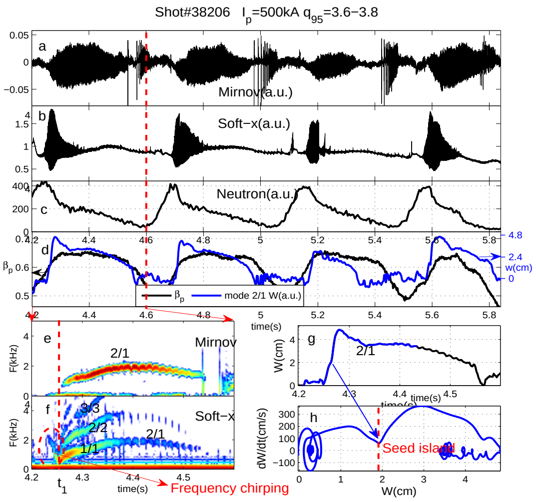

FIG. 1. Characteristics of the NTM on EAST. (a) Mirnov signal, (b) Intensity of the SXR signal near the plasma center, (c) Neutron production rate (solid) and intensity of HXR (dashed-dotted), (d) (2/1) magnetic island width (dashed-dotted) and p (solid), (e) Power spectrum of the Mirnov signal, (f) Power spectrum of the SXR signal, (g) time evolution of the (2/1) magnetic island width (cm), (h) Magnetic island growth rate, dw/dt (cm/s), versus island width (cm).

with a frequency chirping on the spectrum of soft-x ray emission as shown in Fig.1(f).

The excitation of the m/n = 1/1 internal mode is strongly correlated with neutron yields as shown in Fig.1(c). In fact, we observed this phenomena in discharges which auxiliary heating ICRF+LH and LH only, respectively. Thus the mode, characterized by frequency chirping in the spectrum, may be related to suprathermal electrons produced by LH[5].

C. The spontaneous-like triggering $(2,1)$ NTM

The spontaneous triggering NTM is also a usual phenomenon in tokamaks. Microturbulence[6] and intrinsic error field[7] may be play a significant role on the spontaneous triggering NTM. Recently, the phenomenon is also observed in EAST as shown in Fig.2.

Its triggering feature is obviously different from that in shot 38207. In Fig.2(d), there is not a perturbation on the signal of soft-x ray emission of plasma center. The phenomenon also appears during H-mode as shown in Fig.2(a). The spontaneous triggering (2,1) NTM grows

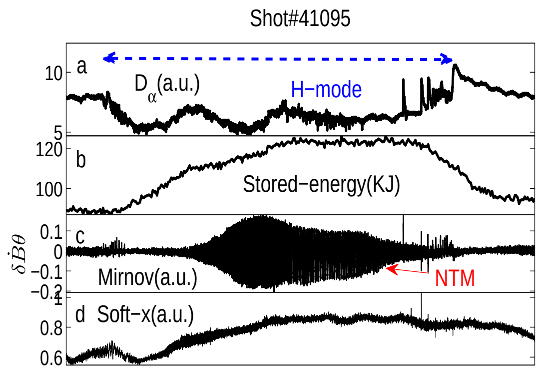

FIG. 2. The temporal evolution of (a) D_α, (b) the stored energy, (c)Mirnov coil signal $\delta\dot{B}_\theta$. $P_{ICRF} = 2.0MW$ for shot 41095 with DSN, plasma current $I_p = 540$ kA, toroidal magnetic $B_T = 1.8$ T on EAST.

to saturation for about $100ms$, which is much slower than that of $(2,1)$ NTM triggered by mode coupling with $(1,1)$ internal mode as shown in Fig.1. The later only spends $30ms$.

D. ELMs triggering $(2,1)$ NTM

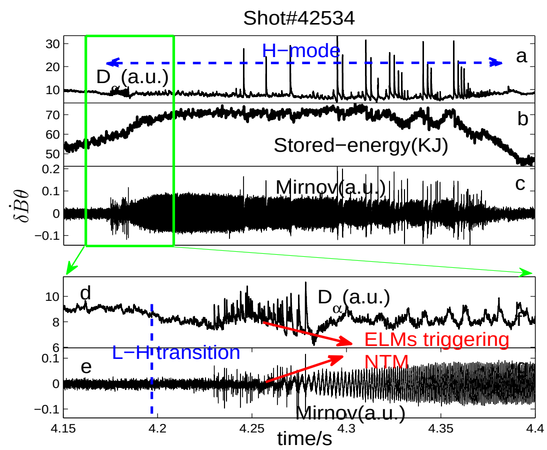

FIG. 3. The temporal evolution of (a) D_α, (b) the stored energy, (c)Mirnov coil signal $\delta\dot{B}_\theta$, (d) soft-x ray emission at the plasma center. $P_{ICRF} = P_{LHCD} = 1.1MW$, DSN, plasma current $I_p = 300$ kA, toroidal magnetic $B_T = 1.8$ T on EAST.

ELMs triggering NTMs are also observed usually in tokamaks[8]. The Fig.3 shows a typical shot of ELMs triggering $(2,1)$ NTM in EAST. There is not perturbation on the soft-x ray emission at plasma center as shown in

Fig.3(d). The continued type-III ELMs appears on the signal of D_α just before a big $(2,1)$ NTM triggering as shown in Fig.3(f,g). The whole event happens during H-mode phase as shown in Fig.3(a,b,c). It is obvious that the continued type-III ELMs provide a seed island for the $(2,1)$ NTM.

E. Sawtooth crash triggering $(2,1)$ NTM

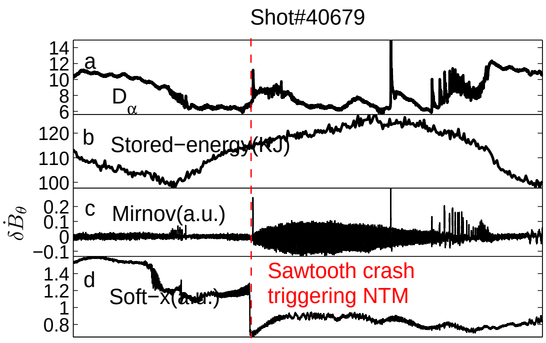

FIG. 4. The temporal evolution of (a) D_α, (b) the stored energy, (c)Mirnov coil signal $\delta\dot{B}_\theta$, (d) soft-x ray emission at the plasma center. $P_{ICRF} = 0.5MW$, $P_{LHCD} = 1.1MW$, DSN, plasma current $I_p = 525$ kA, toroidal magnetic $B_T = 1.8$ T on EAST.

Sawtooth crash triggering NTMs is the most common events in tokamaks. In some conditions, there is a precursor mode just before sawtooth crash, which is coupling with NTMs. The heat flow caused by sawtooth crash and coupling effects will have influence on the forming of seed island of NTMs.

Fig.4 shows a typical shot of sawtooth crash triggering $(2,1)$ NTM in EAST. It is different from that as shown in Fig.1, which does not have obvious sawtooth crash. Here, the perturbation, caused by the sawtooth crash, is the main source of seed island of $(2,1)$ NTM. The whole progress is during H-mode phase as shown in Fig.4(a).

III. THE STATISTICAL RESULTS

The NTM is observed when normalized $\beta_{N,onset}$ exceeds 0.4 in this experiment in EAST. Theoretically[9], $\beta_{N,onset} \sim \sqrt{T_i}/I_p$. The dependence of the $\beta_{N,onset}$ on normalized electron line-averaged density of plasma cen-

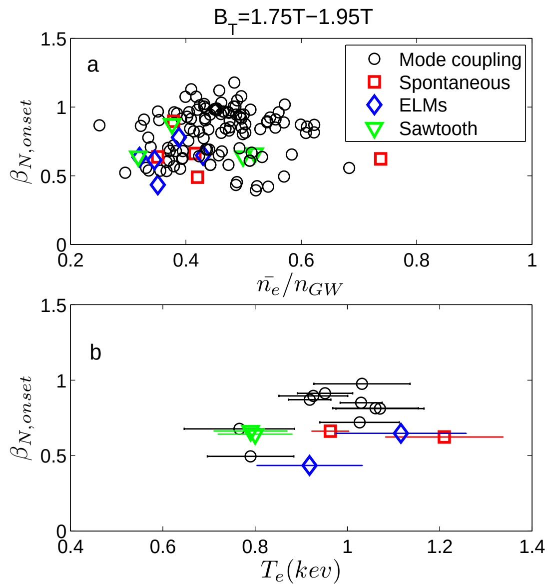

FIG. 5. (a)$\bar{n}_e$ is the line-averaged electron density at R=1820mm, $n_{GW}(10^{20}m^{-3}) = I_p(MA)/\pi a(m)^2$ Greenwald 'limit' density, normalized volume average betas $\beta_N = \beta(\%)a(m)B(T)/I(MA)$, (b)electron temperature T_e at plasma center using soft X-ray PHA (pulse height analysis) diagnostic.

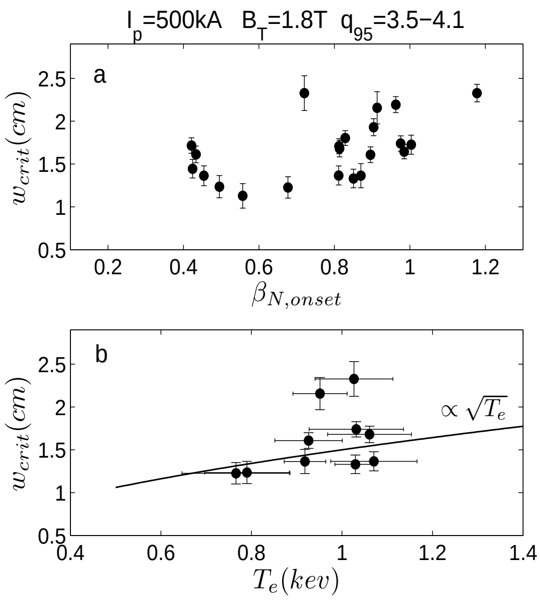

FIG. 6. Seed island width $w_{crit} = a_m\sqrt{\delta B_{\theta,crit}}$ according to Eq.(5), $\delta B_{\theta,crit}$ the poloidal perturbation amplitudes of NTMs(2,1) utilized Mirnov signal. The solid line $w_{crit} \propto \sqrt{T_e}$ is a reference.

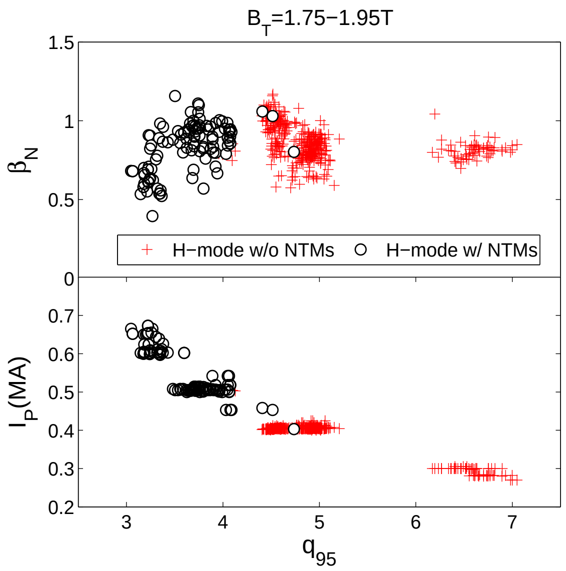

FIG. 7. β_N and q_{95}, the toroidal plasma current I_P. '+' represents steady H-mode without NTMs($\Delta t > 2.0s$), 'o' represents H-mode with NTMs.

ter, $\bar{n_e}/n_{GW}$, is shown in Fig. 5(a). $\beta_{N,onset}$ doesn't have a clear dependence on $\bar{n_e}/n_{GW}$, which is changed in the range $0.35-0.63$. Unfortunately, the T_i measurement is not available in most pulses in this experiment. The dependence of the $\beta_{N,onset}$ on electron temperature, T_e, is shown in Fig. 5(b). The normalized $\beta_{N,onset}$ increases as with increasing T_e. The scaling of the dependence of $\beta_{N,onset}$ on T_e is not easy to be determined because of limited available experimental datas. The characters in the shots with Elms, sawtooth crash, spontaneous triggering NTMs don't have difference compared with that in shots with mode coupling triggering NTM as shown in Fig.5.

The critical seed island width w_{crit} changes in the range $1-2.5cm$ in this experiment. It has no clear dependence on $\beta_{N,onset}$ as shown in Fig. 6(a). Theoretically, $w_{crit} \propto \rho_{\theta i}$[10]. The dependence of the w_{crit} on electron temperature, T_e, is shown in Fig. 6(b). w_{crit} increases as with increasing T_e. A reference line $w_{crit} \propto \sqrt{T_e}$ is also shown in Fig. 6(b).

Fig.7 shows the relation of the q_{95} and β_N. In order to compare the differences between shots with NTMs and without NTMs obviously. Here, the β_N is the $\beta_{N,onset}$ for the shots with NTMs. We choice the β_N during steady H-mode in the shots with $\Delta t > 2.0s$ H-mode. There are big difference for q_{95} between them. In discharges on EAST recently, we get steady H-mode through increasing the q_{95} in order to avoid the NTMs. Other characters don't have obvious differences in these shots with(or without) NTMs, which are not shown here.

IV. CONCLUSIONS

Mode coupling, sawtooth crash, spontaneous and ELMs triggering NTMs have shown above. The $(2,1)$ NTM, which triggered by coupling with $(1,1)$ internal mode, is the most common phenomenon in 2011 and 2012 experiments on EAST tokamak.

The $\beta_{N,onset}$ and magnetic island critical width w_{crit} increase as electron temperature T_e. The parameters($\beta_{N,onset}, T_e, \bar{n_e}/n_{GW}$) don't have obvious differences for the different triggering ways, which include mode coupling, sawtooth crash, ELMs, spontaneous triggerings. It is because of the limited experimental data. It is obvious that $\beta_{N,onset}$ increases as T_e increasing. The steady H-mode($\Delta t > 2.0s$) can be gotten through increasing q_{95}. The pressure gradient decreases at $q = 2$ resonance surface when q_{95} increasing. At this condition, the $(2,1)$ NTMs are not excited easily.

V. ACKNOWLEDGMENT

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