Direct Destabilizations of Macro/Micro Edge Instabilities by Magnetic Perturbations

Jayhyun Kim[1], Minjun J. Choi[1], Jaehyun Lee[2], Jaemin Kwon[1], Young-Mu Jeon[1], Siwoo Yoon[1], the KSTAR team[1], and the KSTAR collaborators[2]

[1] National Fusion Research Institute, Daejeon, Republic of Korea
[2] Ulsan National University of Science and Technology, Ulsan, Republic of Korea

E-mail contact of main author: *jayhyunkim@nfri.re.kr*

Abstract. It has been regarded that magnetic perturbation (MP) by non-axisymmetric fields is the most promising technique in controlling edge localized mode (ELM) crashes that are potentially harmful to the lifetime of first wall in reactor scale devices. However, the exact mechanism of MP has not been fully understood in both ELM crash mitigation and suppression. Here, we investigated the characteristics of macro and micro edge instabilities in relation to MP during ELM crash controlled discharges of KSTAR. Especially, the MP turning-off phases were focused in order to rule out the effect of pedestal evolution. As a result, it was found that the response of macro and micro edge instabilities is very prompt against the applied MP. It suggests that the MP could directly drive macro and also micro instabilities of edge plasmas otherwise the discharge was stable against them. The detailed analyses are still on-going with local fluctuation measurements and numerical/theoretical efforts to reveal the underlying features of MP-driven edge instabilities.

1. Introduction

Stationary ELM-free periods in H-mode discharges can be distinguished from transient ones by the existence of regulation mechanism which prevents the evolution of edge pedestal profiles toward ELM crashes. Several transport mechanisms have been discussed as the candidates of the regulation mechanism such as edge harmonic oscillations in quiescent H-mode, weakly coherent mode in I-mode, and stochastic transport in resonant magnetic perturbation (MP)-driven ELM crash suppression.

In a tearing hypothesis of stochastic transport, applied MP(s) do not directly affect edge instabilities. Instead, they enhance edge transports by forming magnetic island(s) and their overlaps on resonant rational surface(s). Eventually, resulting edge profiles determine the characteristics of edge instabilities. Thus the evolution of edge profiles needs to be precedent before the change of edge instabilities in the tearing hypothesis of ELM crash suppression. However, it has been recently proposed/reported direct destabilization of edge instabilities by MPs in both experimental [1, 2] and theoretical researches [3, 4] which seems to advance the evolution of edge profiles.

Here, we will discuss the features of edge instabilities depending on MPs with focusing on the possibility of direct destabilization of them in ELM crash controlled discharges of KSTAR. In order to rule out the effects of profile changes such as strong density pump-out, we mostly investigated exiting phases from ELM controlled periods with fast turning-off of MPs. This study will cover both macro- and micro- scale instabilities for explaining the role of MPs both in ELM crash mitigation and suppression.

2. Mitigation of ELM Crashes

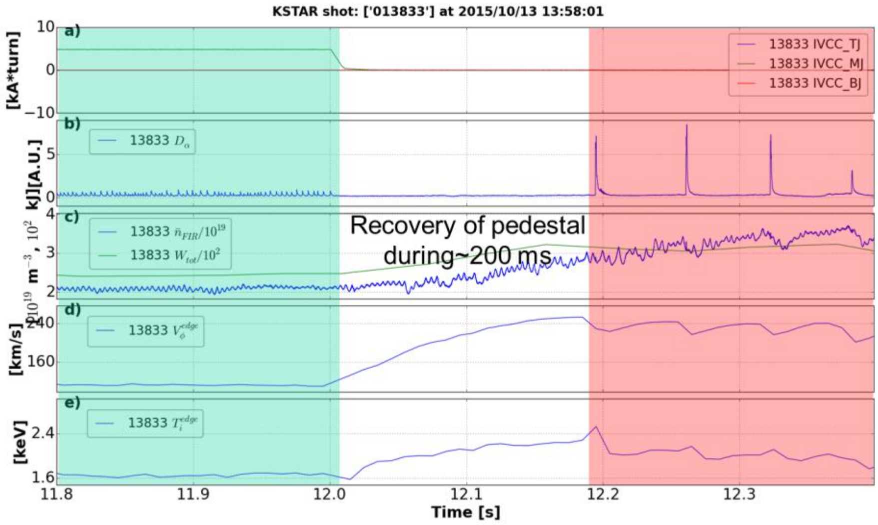

FIG. 1. Evidence of direct destabilization of macro edge instabilities by MPs in KSTAR shot no. 13833. a) Non-axisymmetric coil currents, b) $D\alpha$ signal, c) line-integrated density (blue line) and stored energy (green line), d) edge rotation, and e) edge ion temperature.

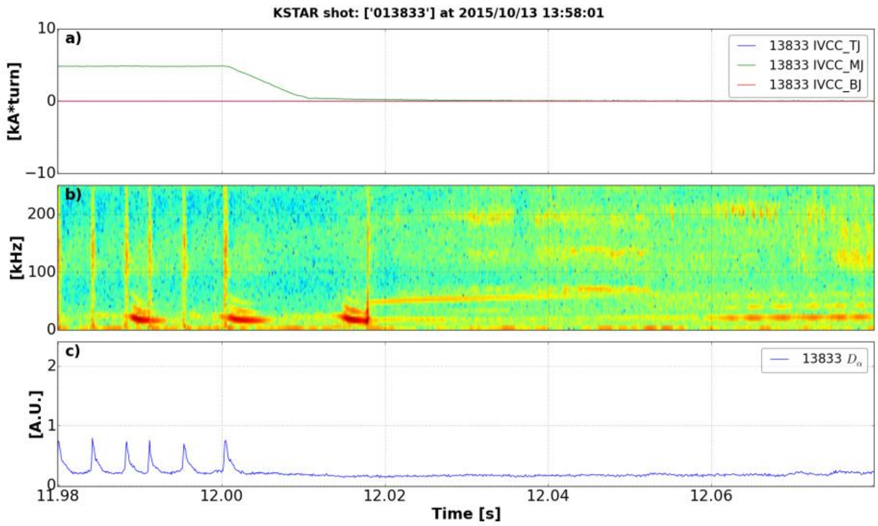

FIG. 2. Magnetic fluctuation change of ELM crash mitigated discharge in KSTAR shot no. 13833. a) Non-axisymmetric coil currents, b) spectrogram of magnetic fluctuation, and c) $D\alpha$ signal.

Figure 1 depicts a response of ELM crashes depending on MPs during the strongly mitigated discharge. Although the mitigated ELM frequency is more than 10 times larger than that of natural ones, individual ELM crashes still exist in macro scale as indicated by $D\alpha$ peaks in green shaded region. On the other hand, the mitigated ELM crashes immediately disappear when the MPs is turned off. The turning-off period (~10 ms) is much shorter than the pedestal evolution time (~200 ms) which is required to bring natural ELM crashes back without the influence of MPs. Thus it could be concluded that the MPs directly triggered/affected ELM crashes [3] otherwise the discharge was stable against ELM crashes, for instance peeling-ballooning (PB) mode stability criteria, due to the degraded edge pedestal .

Note that no significant change is observed in broadband magnetic fluctuation during the MP turning-off phase (t=12.00 sec ~ 12.01 sec) except collapse lines caused by individual ELM crashes in figure 2. Increase of broadband fluctuations seems to start along with the recovery of edge pedestals.

3. Suppression of ELM Crashes

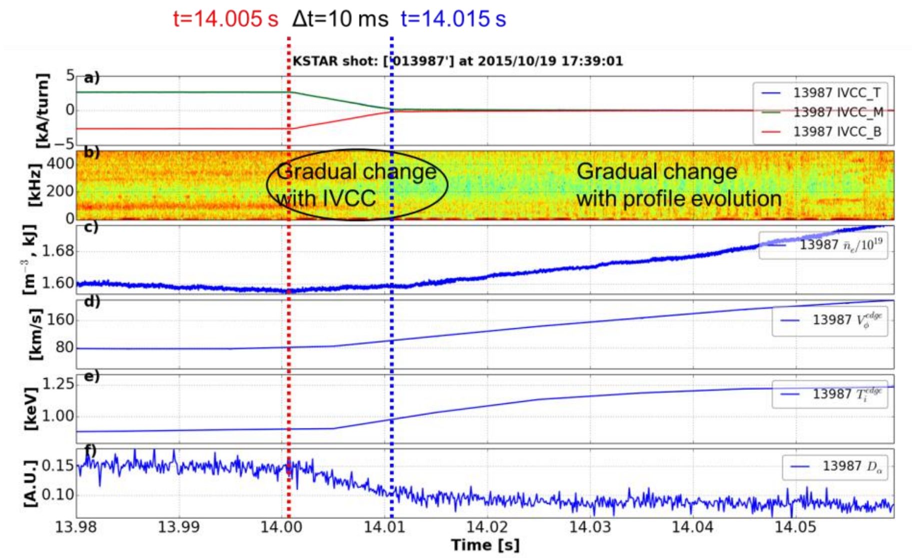

FIG. 3. Evidence of direct destabilization of micro edge instabilities by MPs with *fast* MP turning-off. a) Non-axisymmetric coil currents, b) spectrogram of magnetic fluctuation, c) line-integrated density, d) edge rotation, e) edge ion temperature, and f) $D\alpha$ signal.

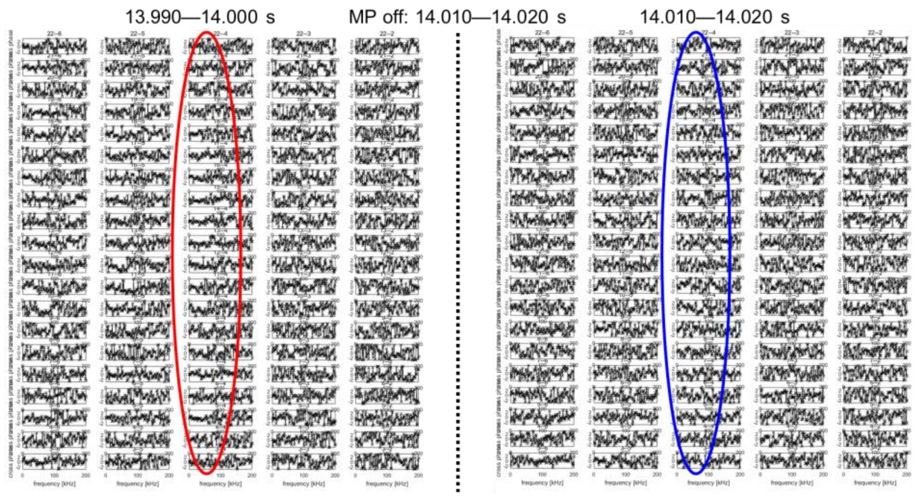

FIG. 4. Cross-phases of edge ECEI channels in KSTAR shot no. 13987 before and after the MP-turning off. Red and blue circles indicate the channels of significant change.

During the ELM crash suppressed discharge, the D_α and magnetic fluctuation signals promptly respond to the MP amplitude as shown in figure 3. The D_α signal (an indicator of edge particle transport) shows an abrupt change only when the MP amplitude drops. Then equilibrium evolutions, as observed in line-integrated density, edge rotation, and edge ion temperature, gradually follow the MP amplitude drops. This suggests that the enhanced transport due to micro edge instabilities, which are destabilized by MPs, plays a certain role in keeping the pedestal below the level of large ELM crashes. The analysis of edge turbulence by electron cyclotron emission imaging (ECEI) revealed that the fluctuation level in low field side was significantly reduced just after the MPs turned off as shown in figure 4. However, we have not detected meaningful change in the high field side channels [5, 6]. Note that the change of turbulence seems to be localized in certain edge region (*i.e.*, certain edge channels) only.

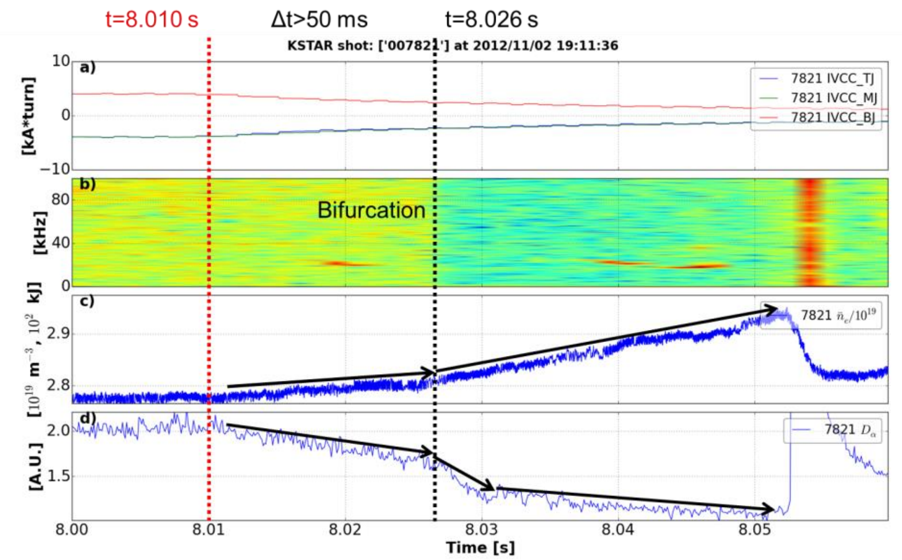

FIG. 5. Evidence of direct destabilization of micro edge instabilities by MPs with *slow* MP turning off. a) Non-axisymmetric coil currents, b) spectrogram of magnetic fluctuation, c) line-integrated density, and d) $D\alpha$ signal.

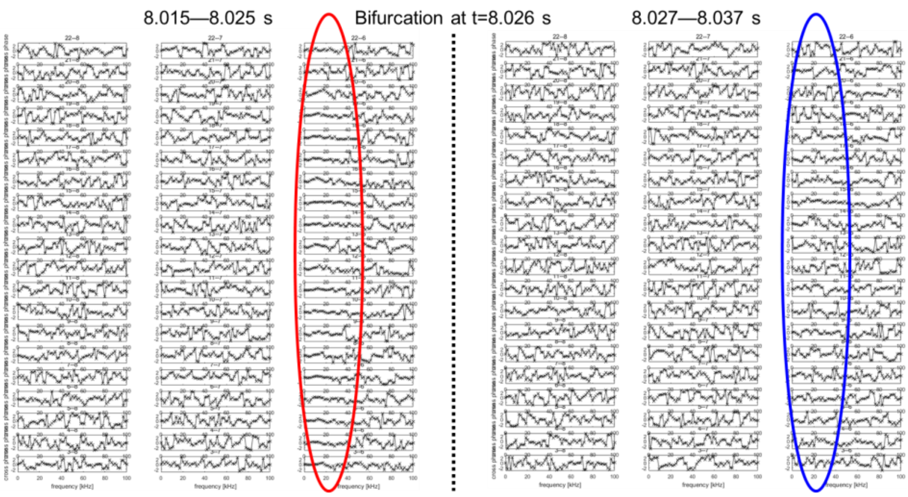

FIG. 6. Cross-phases of edge ECEI channels in KSTAR shot no. 7821 before and after the bifurcation-like feature at t=8.025 sec. Red and blue circles indicate the channels of significant change.

On the other hand, the bifurcation-like feature was observed in the magnetic fluctuation, line-integrated density, and D_α signal [6] when we slowly ramped the MP down during nearly 60 ms as shown in figure 5. Although there is a caveat in isolating the effect of pedestal evolution from the change of edge instabilities, figure 5 still represents several important aspects. Firstly, global confinements are generally governed by the MP amplitude as shown in the evolution of line-integrated density and D_α signal during t=8.01 sec ~ 8.05 sec. In addition, the bifurcation or threshold of edge instabilities intervenes the edge transport abruptly. Figure 6 depicts that the mentioned bifurcation-like feature takes place in edge localized region. The detailed analyses are still on-going with local fluctuation measurements to reveal the characteristics of MP-driven micro edge instabilities (*i.e.*, the type of edge instability) along with bifurcation-like feature during the slow change of MPs [6].

4. Sporadic ELM Crashes during ELM Crash Suppressed Period

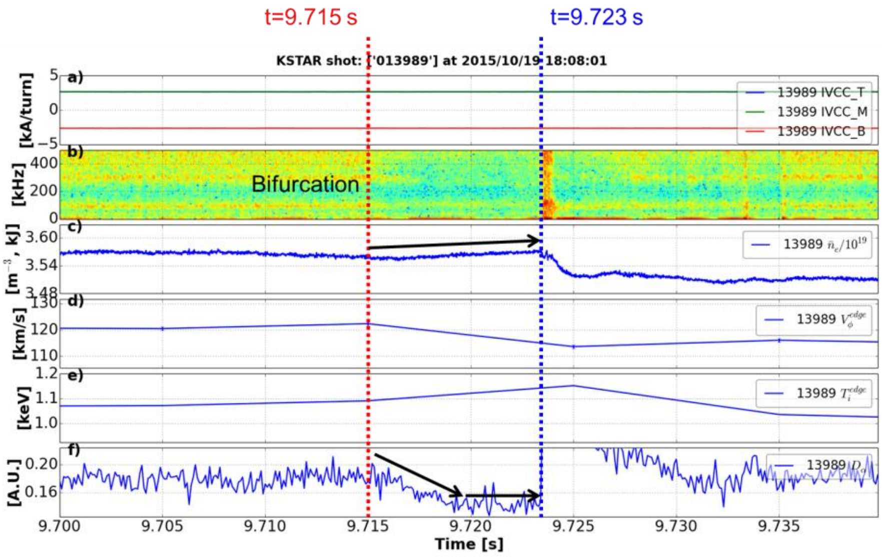

FIG. 7. Sporadic ELM crash *with* accompanying magnetic fluctuation change and confinement enhancement. a) Non-axisymmetric coil currents, b) spectrogram of magnetic fluctuation, c) line-integrated density, d) edge rotation, e) edge ion temperature, and f) $D\alpha$ signal.

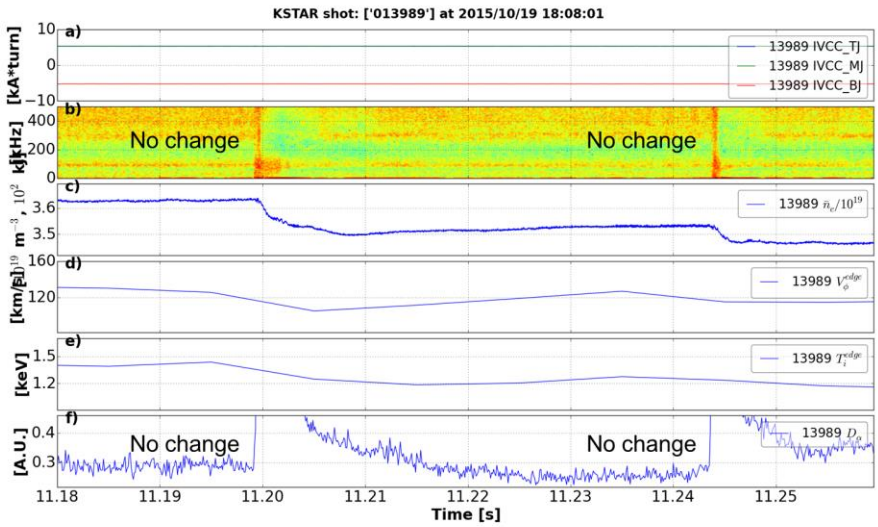

FIG. 8. Sporadic ELM crash *without* accompanying magnetic fluctuation change and confinement enhancement. a) Non-axisymmetric coil currents, b) spectrogram of magnetic fluctuation, c) line-integrated density, d) edge rotation, e) edge ion temperature, and f) $D\alpha$ signal.

It is beneficial to analyze so called sporadic ELM crashes, which are isolated ELM crash(es) as a temporal exiting event during ELM crash suppressed period. Here, we present two different types of sporadic ELM crashes in figures 7 and 8. It needs to be mentioned that these two different types of sporadic ELM crashes occurred in the same ELM crash suppression period of KSTAR shot no. 13989, which was obtained with using n=1 MPs.

One is the sporadic ELM crash with accompanying the bifurcation-like feature and resulting confinement enhancement as shown in figure 7. The process very resembles with that of MP turning-off phase as depicted in figures 3 and 5. However, the levels of density increase and $D\alpha$ drop, needed for re-appearance of sporadic ELM crashes in the suppressed periods, seem to be significantly lower than those of MP turning-off phase (*not shown here*). It could be conjectured that the macro-instability criteria, causing sporadic ELM crashes, is also affected by applied MPs like the mitigated ELM crashes shown in figure 1.

The other type has no signature of bifurcation-like feature in magnetic fluctuation and $D\alpha$ signal as shown in figure 8. Two isolated ELM crashes suddenly emerged without preludes. In figure 8b), the drop of fluctuation level was due to the collapse of edge pedestal after sporadic ELM crash. Then magnetic fluctuation gradually increased between two sporadic ELM crashes. The features near sporadic ELM crashes, which have no prelude, are like the behaviors of natural ELM crashes. These sporadic ELM crashes without preludes might be understood by the competition between ELM crash suppression and mitigation mechanisms. In other words, the sporadic ELM crashes might be easily excited even in regulated edge pedestals of ELM crash suppressed period due to the change of macro-instability criteria.

It implies that a careful consideration might be needed to avoid unwanted ELM triggering when applying MPs since the triggering mechanism could be valid in typical ELMy and also ELM crash suppressed periods [7]. It is still uncertain what conclusively determines the bifurcation-like feature in figure 7 or sporadic ELMs without preludes in figure 8 since there is no discernible change in equilibrium profiles.

5. Summary and Discussion

In this study, we present the evidences of direct destabilization both in ELM crash mitigation and suppression of KSTAR H-mode discharges when low n MPs (*e.g.*, n=1 and n=2) are applied. Actually, the characteristics of edge instabilities are very similar both in n=1 and n=2 ELM crash suppression. The results shown in this study depict that the changes of edge instabilities advance the equilibrium evolutions. It is somewhat inconsistent with the explanation of ELM crash suppression by the stochastic transport in the tearing hypothesis although it also shares the feature of bifurcation with the tearing hypothesis [6].

In order to find an alternative explanation about ELM crash mitigation and suppression, we might need to re-assess the stability criteria of both macro and micro edge instabilities under the applied MPs since the most of stability calculations have assumed unperturbed/undistorted equilibrium so far. Numerical simulation is planned to re-calculate the PB mode stability in perturbed equilibrium with including mode coupling [3]. In addition, possible candidates of MP-driven micro edge instabilities such as kinetic ballooning mode are being considered [4] now.

Furthermore, it should not be fully excluded other possibilities in the mechanism of ELM crash suppression such as zonal flow damping by MPs as a meso-scale phenomenon [8] although it still has a limitation in explaining the mitigated ELM crashes observed in various devices. Unified picture of MP-driven mitigation and suppression of ELM crashes should be established for better understanding of their mechanisms and for realistic application to reactor scale devices such as ITER.

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