ELM mitigation using *n=2* magnetic perturbations on JET with an ITER-like wall and comparison with a C-wall

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Active control of edge-localized modes (ELMs) by externally applied fields offers an attractive method for next-generation tokamaks, e.g. ITER. To date, most ELM mitigation/suppression experiments have been performed on devices with a carbon-wall (C-wall)[1, 2]. However, a carbon-free tungsten divertor is foreseen for the phase active on ITER, while the main chamber blanket modules in ITER are protected by shaped (limiter-like) beryllium panels. Therefore, it is urgent and important to prove the applicability of ELM control/suppression with magnetic perturbations in plasmas with ITER-like PFCs and to perform a systematic comparison with previous results with a C-wall.

On JET, the previous experiments have shown that type-I ELMs can be mitigated in a relatively wide operational domain (q_{95}, pedestal collisionality, triangularity, configurations …) with a C-wall by applying static low *n* external magnetic perturbation fields [2,3]. Since 2012, the ITER-like wall (ILW) has been installed on JET to replace the previous C-wall, and the EFCC system is upgraded to allow a maximum coil current twice as large as the previous one. To date, JET is the only device capable of studying ELM mitigation with magnetic perturbations in plasmas with an ILW and comparison with a C-wall. Recently, mitigation of type-I ELMs was observed with an $n = 2$ field on JET with the ILW [4] in a relative wide range of the pedestal collisionality ($0.3 < \nu_e^* < 2.5$) and plasma density ($0.55 < n_e/n_e^{GW} < 0.9$) as shown in figure 1. Here, n_e^{GW} is the Greenwald density limit. Several new findings with the ILW were identified and contrasted with the previous C-wall results for comparable conditions.

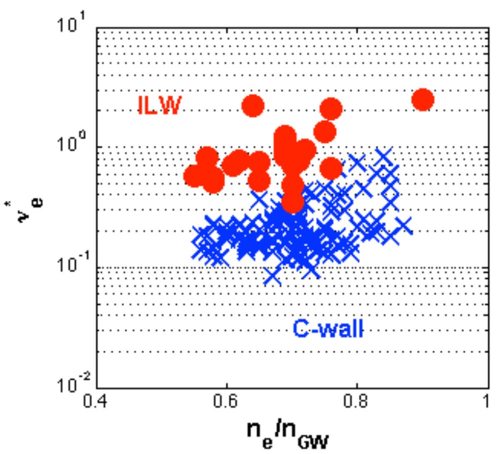

Figure 1 Experimentally determined access condition in terms of pedestal collisionality (ν^*_e) versus pedestal density as a fraction of the Greenwald density (n_e/n_{GW}) for mitigation of type-I ELMs using EFCC on JET with the C-wall (*n*=1 and 2 EFCC) and the ILW (*n*=2 EFCC only)

In the high collisionality ($\nu^*_{e,ped} \geq 2.0$) regime, no clear ELM mitigation or suppression was observed during an application of the $n = 1$ or 2 fields with a EFCC current up to 48kAt on JET

*see the Appendix of F. Romanelli et al, Proc 25th IAEA Fusion Energy Conference 2014, St. Petersburg, Russia with the C-wall, where the target plasma has a relatively high ELM frequency (few 100 Hz). However, with the ILW, a strong mitigation of type-I ELMs was observed in both high and low triangularity H-mode plasmas when the n = 2 field was applied as shown in figure 2. In this experiment, the EFCC coil current was kept at 80kAt for 2 seconds, which is about ten times the plasma energy conferment time. The large regular type-I ELM becomes small in size and irregular in frequency in the low triangularity case (♯ 87511), while it almost disappeared when the plasma triangularity increases from ~0.3 up to ~0.45 during the flattop of the EFCC current (♯ 87516). The plasma shapes used in this experiment are named as V5OH and HT3R configurations on JET for the low and high triangularity plasmas, respectively. In the high collisionality regime with the ILW, no density drop (so called pump-out effect) was observed, and splitting of the outer strike point was observed in the H-mode plasma during the application of the n = 2 field on JET. With an increase in NBI heating power, the effect of the n = 2 fields on ELMs becomes much less pronounced in H-mode plasmas with the HT3R configuration as shown in figure 2 (bottom plot). The large type-I ELM re-appears when the NBI power increases from 3MW to 6MW in the H-mode plasma. The ELM frequency slightly increases with a further increase in the NBI power from 6MW to 9MW. This agrees with the typical power dependence of the Type-I ELM.

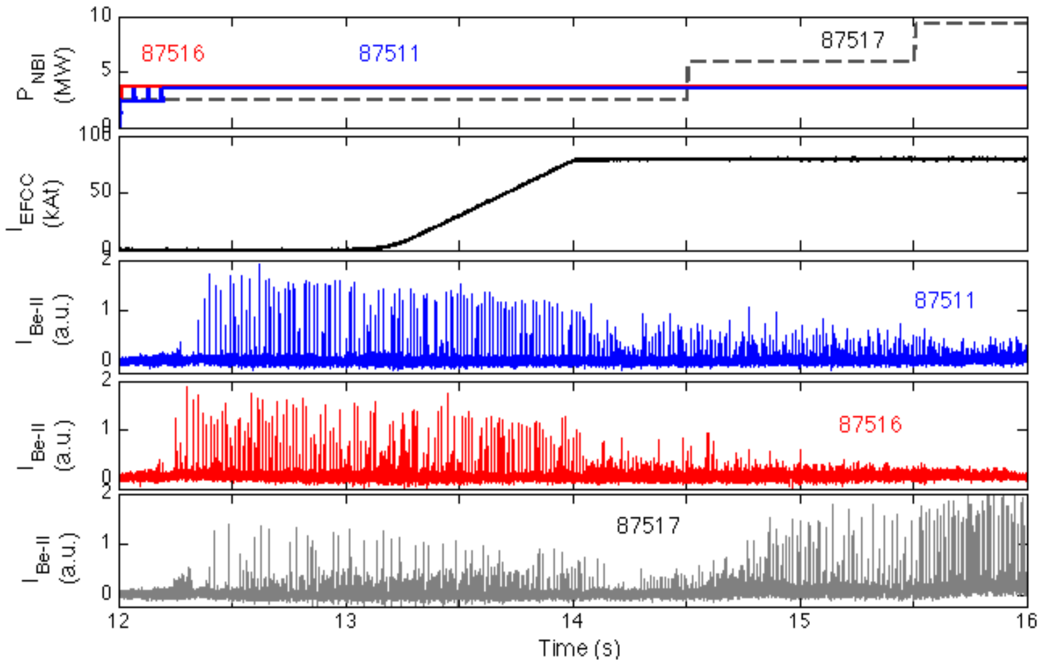

Figure 2 Time evlutions of NBI power, EFCC current and intensity of Be-II emissions for the H-mode plasma with a low (87511) and high (87516, 87517) triangularities, respective.

In the moderate collisionality ($0.3 < \nu^*_{e,ped} < 2.0$) regime, ELM mitigation with an increasing ELM frequency up to 6 times of the unmitigated case with the n = 1 fields and up to 5 times with the n = 2 fields has been achieved in different plasma configurations and a wide range of q_{95} on JET with the C-wall. Since 2012, ELM mitigation has been observed in the moderate collisionality regime on JET with the ILW using the n = 2 fields. A saturation effect of ELM mitigation and a reduction in the maximal ELM peak heat load, due to the splitting of the outer

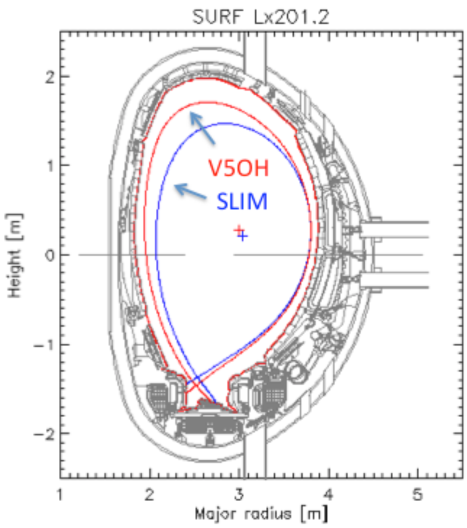

Figure 3 Comparison the plasma shape between SLIM (blue) and V5OH (red) configurations.

strike point, were observed during the application of the n = 2 fields. With the n = 2 fields, clear pre-ELM structures were observed on the outer divertor plate, and its dependence on q_{95} [4].

Recently, the plasma shape dependence of the ELM mitigation using the n = 2 field has been observed on JET with the ILW. Two different plasma configurations, V5OH and SLIM as shown in figure 3, were chosen as the target plasmas in this experiment. Both of these two configurations have a low plasma triangularity, but different significantly in the inner and top gap between plasma and first wall. Therefore, the SLIM plasma has a larger edge clearance and smaller plasma volume comparing with the V5OH plasma. Although both the SLIM and the V5OH configurations have a similar divertor configuration, but the outer strike point of the SLIM configuration is closer to the divertor pumping port, and the pumping efficiency of the SLIM configuration is better.

With the V5OH configuration mixed small and large ELMs appear during an application of the n = 2 field in the H-mode plasmas with the pedestal electron collisionlity of 1.1 as shown in figure 4. The plasma core density drops from $4.0\text{x}10^{19}\text{m}^{-3}$ to $3.5\text{x}10^{19}\text{m}^{-3}$, while the core electron temperature reduces as well. With an increasing in the NBI heating power from 6MW to 9MW and 12MW, the pedestal collosionality reduces down to 0.7 and 0.4, respectively, and the small ELMs disappeared and the more regular Type-I ELMs are remaining in the H-mode plasma. The remaining Type-I ELMs during the flattop of the n = 2 EFCC phase have an ELM frequency of few 10 Hz, even lower than that before applying the n = 2 field, however, the ELM peak heat flux was reduced.

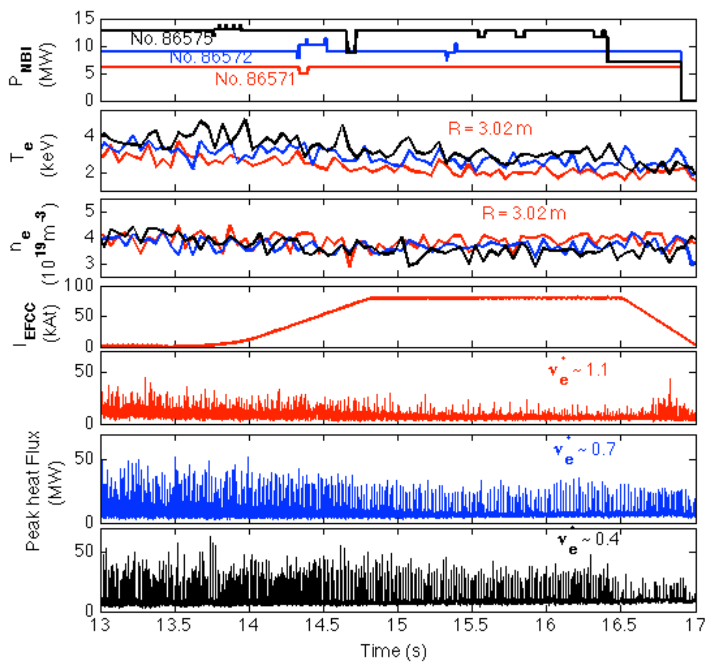

Figure 4 Overview of the ELM mitigation using n=2 fields in the H-mode plasmas with different NBI heating power of 6MW (86571), 9MW (86571) and 12 MW (86572). The signal from top to bottom are NBI power, plasma electron temperature and density measured by TS at the plasma core, EFCC coil current and Peak heat flux measured by the IR camera viewing outer divertor plate.

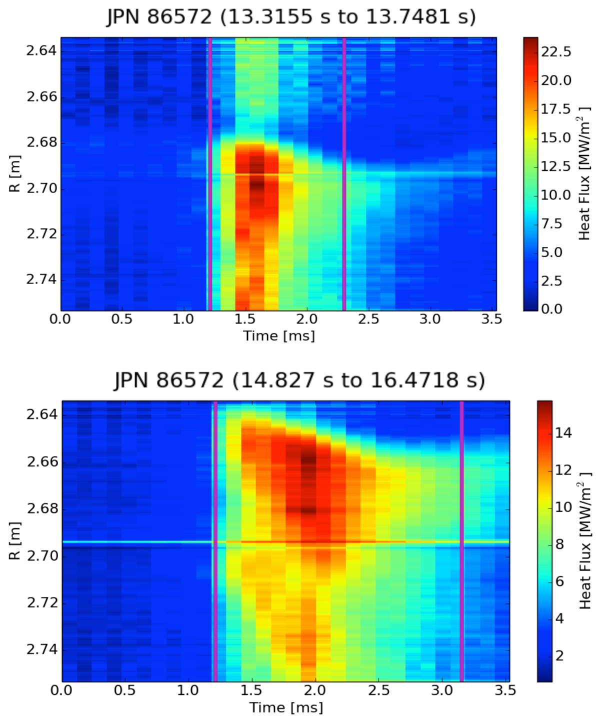

Figure 5 Averaged ELM heat flux distribution on the outer divertor measured without (upper) and with (bottom) an application of an n = 2 field.

Figure 4 shows a comparison of the averaged ELM heat flux distributions on the outer divertor plate before and after the application of the n = 2 fields. With the n = 2 field, the ELM peak heat flux reduces from 22 MW/m^2 to 15 MW/m^2, and splitting of the outer strike point has been seen during the ELM crash. The heat flux at the secondary strike point is about 12 MW/m^2, which is ~75% of the ELM peak heat flux. Both the secondary and the original strike points are moving slowly out along the divertor plate after the ELM crash, and the heat load decay time of the mitigated ELM is about 2ms, which is by a factor of two longer than that of the non-mitigated ELM.

To summarize, in the high collisionality regime, significant ELM mitigation using the n = 2 fields has been observed on JET with the ILW, while no/weak ELMs mitigation was observed in previous experiments with a C-wall. Very small and frequent ELMs were observed during the application of the n = 2 fields in both, low (V5OH) and high triangularity (HT3R) plasmas with a low NBI power, and there is no density pump-out was observed.

In moderate collisionality plasmas, the influence of plasma configuration on the collisionality dependence of ELM mitigation with the n = 2 fields has been observed on JET with the ILW. With the n = 2 fields, an increasing in ELM frequency by a factor of 4 are observed in the plasma with the SLIM configuration, while the ELM frequency even slightly drops in the plasma with the V5OH configuration. Reduction in the maximal ELM peak heat load, due to the splitting of the outer strike point, were observed during the application of the n = 2 fields. The JET experimental observations indicate that the edge boundary condition (or the wall effect) is important for the ELM mitigation/suppression with magnetic perturbations on ITER.

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