Comparing magnetic triggering of ELMs in ASDEX Upgrade and TCV with the DINA-CH tokamak simulator

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1. Introduction

Magnetic triggering of type-I ELM is one of the ideas aiming at the control of type-I ELMs to have a higher frequency for mitigation of the peak heat load on divertor plates. Based on this idea, there were successful experiments using a voltage perturbation in the G-coils which are located inside the vacuum vessel of TCV for vertical instability control [1]. To prove the applicability of this method, similar experiments were performed in ASDEX Upgrade by controlling the PF-coil currents [2]. In these experiments, the vertical plasma movement was induced by forcing the plasma to follow a pre-programmed vertical position instead of the successive pulse inputs on the G-coil voltage used in the TCV experiments. The vertical position is programmed to have a sinusoidal shape with both higher and lower frequencies than the natural type-I ELM frequency. The type-I ELMs are triggered when the plasma is moving down, contrary to TCV experiments, in which ELMs are triggered when the plasma moves up. This discrepancy gave rise to a difficulty in the physical understanding of the triggered ELMs. In TCV experiments, the triggered ELMs seem to result from a positively induced current by the plasma movements. However, ASDEX Upgrade plasmas have triggered ELMs when the induced current is negative at the edge region. In order to investigate the opposite behaviour observed in the experiments, the DINA-CH integrated tokamak simulator has been used [3].

2. Magnetic triggering of ELMs

In the simulation, the density and the temperature profiles are fixed in time. Pedestal temperature and density profiles and the edge bootstrap current induced by them have also not been taken into account due to the absence of a pedestal model in DINA-CH. Therefore, the plasma current variation in the edge region only indicates an external current source driven by the vertical plasma movements and the external linking flux change.

For the TCV simulation, pulse #20333 has been repeated with the same method which was already reported in a previous paper [1]. In the simulation shown in Figure 1, the G-coil current and vertical plasma movements are more prompt than those in the experiment. Though the G-coil resistance and inductance need reexamination to explain these fast responses, the simulation results are good enough to investigate the magnetic response of the TCV plasma. As already reported and discussed, the triggered ELMs are observed around the end of the current variation and vertical plasma movements.

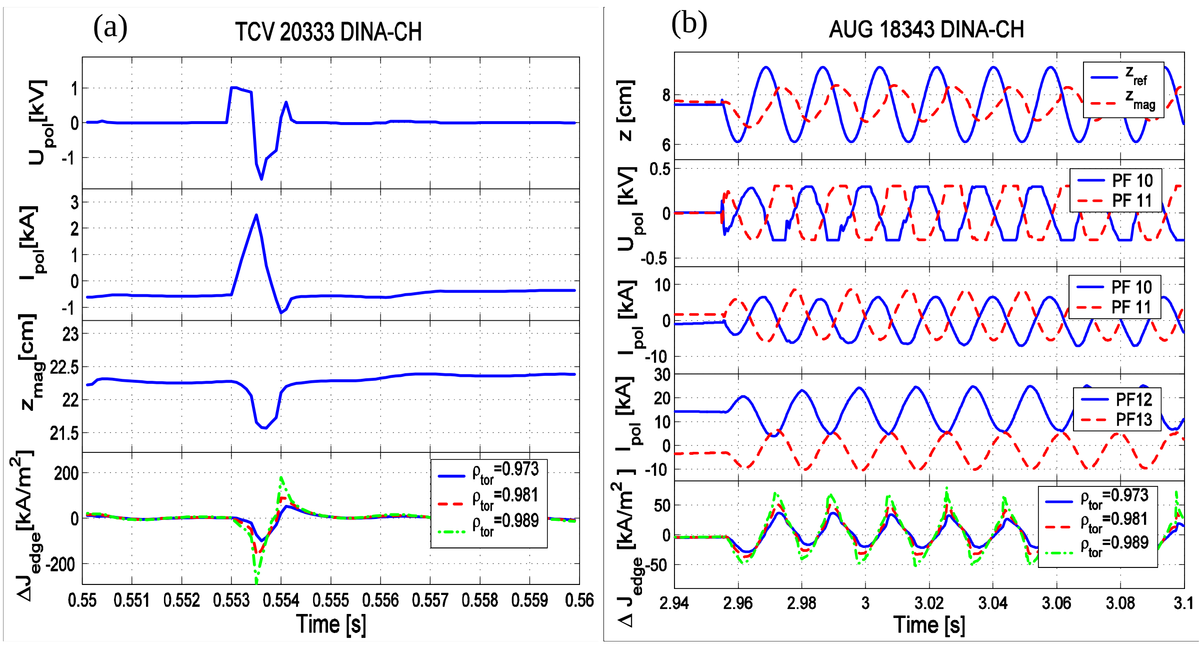

Figure 1. Time responses of plasmas during the magnetic triggering of ELMs in (a) TCV and (b) ASDEX Upgrade. PF 10 – 13 are known as ICoIo, ICoIu, Ipslon and Ipslun, respectively.

In the ASDEX Upgrade simulation, the control action is governed by the difference between the real plasma position and the reference plasma position. This creates a very complex relation between the plasma position, PF-coil currents, image currents on the vacuum vessel and passive stabilisers, plasma current and controller. Similar current variations in the active control coils ICoIo and ICoIu compared with the experiment have been achieved. However, the variation of the vertical plasma position is less than that observed in the experiment. In the experiments, ELMs are observed when the plasma is moving down and the edge current of the plasma starts to rise from its minimum value.

3. Candidates for the ELM triggering

The first possible candidate for the ELM triggering is a plasma current density variation in the edge region. In the simulations for both TCV and ASDEX Upgrade, the maximum plasma current density variation by the plasma movement and the external linking flux change is about 50% of its average value at the edge region. Besides this, there is another interesting observation on the plasma current density variation. The temporal change of the plasma current density in the inner region has a different sign to its change at the edge. Though these imply several possibilities of different paths in a stability diagram depending on the type of ELMs or dynamical changes of the stability diagram itself, there is no obvious explanation for the opposite ELM behaviour in the two plasmas.

The second candidate is a local pressure gradient change in the edge region. This change has a rather small variation. The maximum change is around 6% of its average value. This is also not enough to give a good explanation for opposite ELM behaviour in two plasmas, because the local pressure gradients increase when the plasmas are moving down in both TCV and ASDEX Upgrade cases.

The last candidate is a flux surface deformation pattern at the edge region depending on the plasma movements shown in Figure 2. For the TCV plasma, the flux surface deformation patterns are obtained during the plasma current variations at the edge region in agreement with the experimental observation. The passive stabilisers located inside the vacuum vessel of ASDEX Upgrade play a role as an external linking flux source and create a local expansion or shrinkage of the flux surface near them. At the same time, they have a shielding effect against other external flux changes caused by the vacuum vessel components and the active PF-coils. Therefore, when the plasmas are moving in opposite direction, upward in TCV and downward in ASDEX Upgrade, they have similar flux surface deformation patterns at the time of the triggered ELMs. This is an observation that could be a clue for a physical explanation of triggered ELMs. To find out the relation between the flux surface deformation and the stability at the edge region, stability analysis has been performed and is reported in [4].

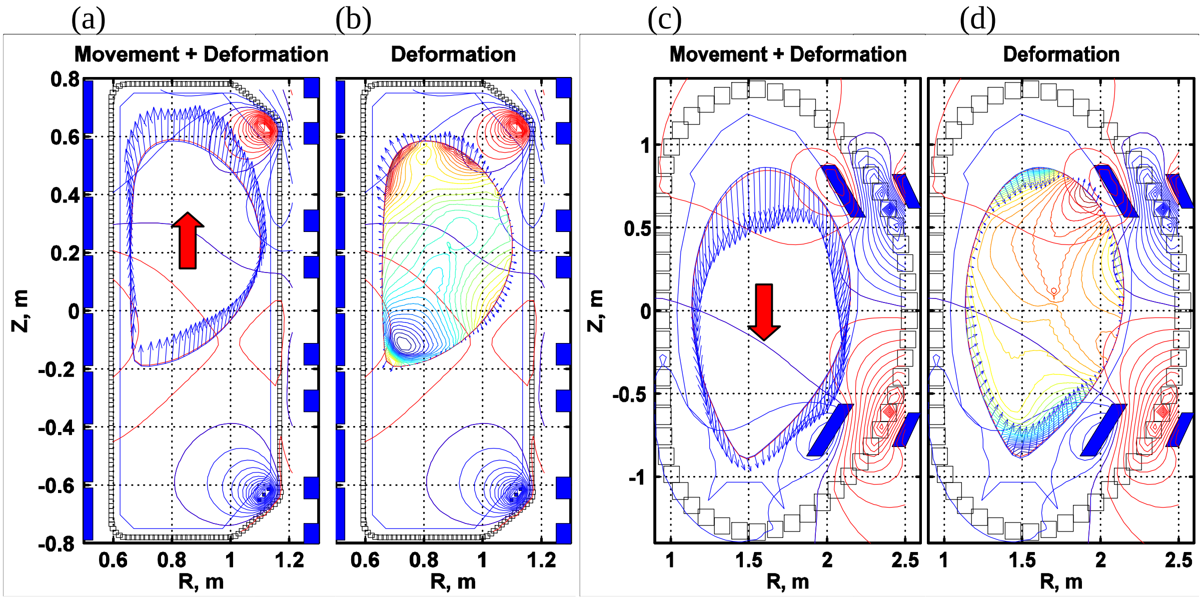

Figure 2. The third candidate, the flux surface deformation patterns. ELMs are triggered. (a) and (c) : plasma movements and the flux surface deformation in TCV and ASDEX Upgrade, respectively. (b) and (d) : the flux surface deformation in TCV and ASDEX Upgrade, respectively. All arrows are amplified by 20 times to make them visible.

4. Conclusions

By simulating the plasma response with a full simulation of the plasma control system, vacuum vessel and PF-coils, the magnetic triggering of ELMs in ASDEX Upgrade has been compared with that in TCV. A new candidate for the explanation of ASDEX Upgrade, the flux surface deformation pattern, has been suggested. The passive stabiliser in ASDEX Upgrade has the same effect as the G-coil in TCV and this causes the opposite ELM behaviour with respect to the plasma motion. For the validation of this new candidate, experiments with a radial plasma movement have been proposed for ASDEX Upgrade.

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