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Effect of ELMs on the Measurement of Vertical Plasma Position in TCV

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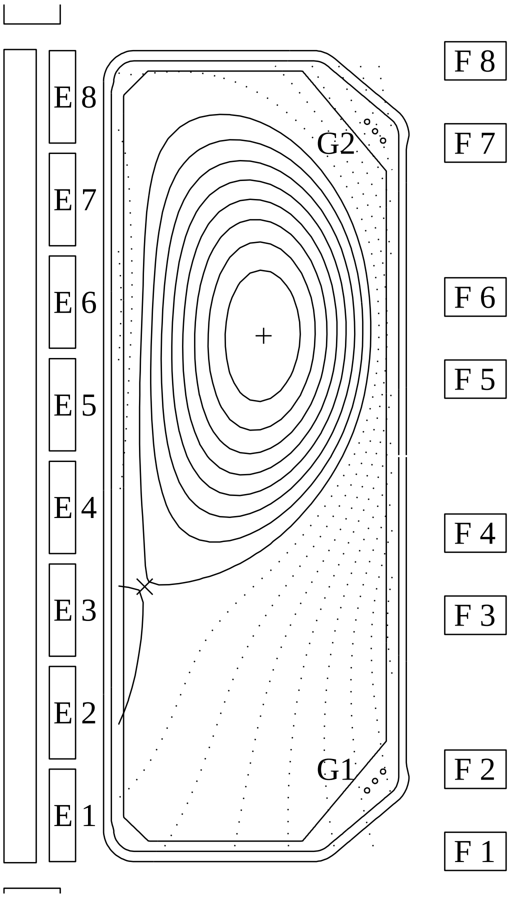

Fig.1. ELMy H-mode plasma in TCV: Shot # 18416 at 0.57 s, I_p=513kA, B_{tor}=1.45T, κ=2.03, δ=0.45, ELM frequency=170 Hz. Feedback for vertical position control is applied to coils F3, F4, F7, F8, G1 and G2.

1. Introduction

It is well known that tokamak plasmas with elongated and shaped cross-sections offer higher beta limits and better confinement than circular plasmas. This fact is the main motivation for the recent evolution of the ITER design towards higher elongation and triangularity. However, elongated cross-sections inevitably lead to vertically unstable plasmas, requiring a passive shell and active feedback coils for stabilization. One of the key elements of the feedback system in an elongated tokamak is the vertical position observer, i.e. the measurement of the vertical plasma position in real time. This measurement is usually obtained from a linear combination of magnetic field probe and flux loop signals and, consequently, it can be perturbed by plasma effects, such as sawteeth, ELMs and non-axisymmetric MHD modes, which are not necessarily related to the vertical displacement instability. Some of these perturbations, e.g. n>0 modes, can be eliminated by a judicious combination of magnetic probe arrays, located in different toroidal locations, but other effects, such as ELMs, will always interfere with the vertical position control system. In the case of large ELMs, the interference can lead to saturation of control coil voltages and currents and, subsequently, to Vertical Displacement Events (VDE’s) and disruptions [1]. Several methods have been proposed to reduce or eliminate the effect of ELMs on the vertical position control system. One method consists of switching off the vertical feedback for a short time interval during each ELM. This method requires a reliable ELM detector which can be used as a trigger for switching off the feedback. It can only be used if the growth time of the vertical instability is considerably longer than the duration of a typical ELM. Another method uses an intelligent, nonlinear controller which recognizes the ELM and applies an optimized control scenario during the ELM perturbation. In this paper, we investigate the effect of ELMs on the vertical position observer in TCV and we show that a minor modification of the classical observer can greatly reduce its sensitivity to ELMs.

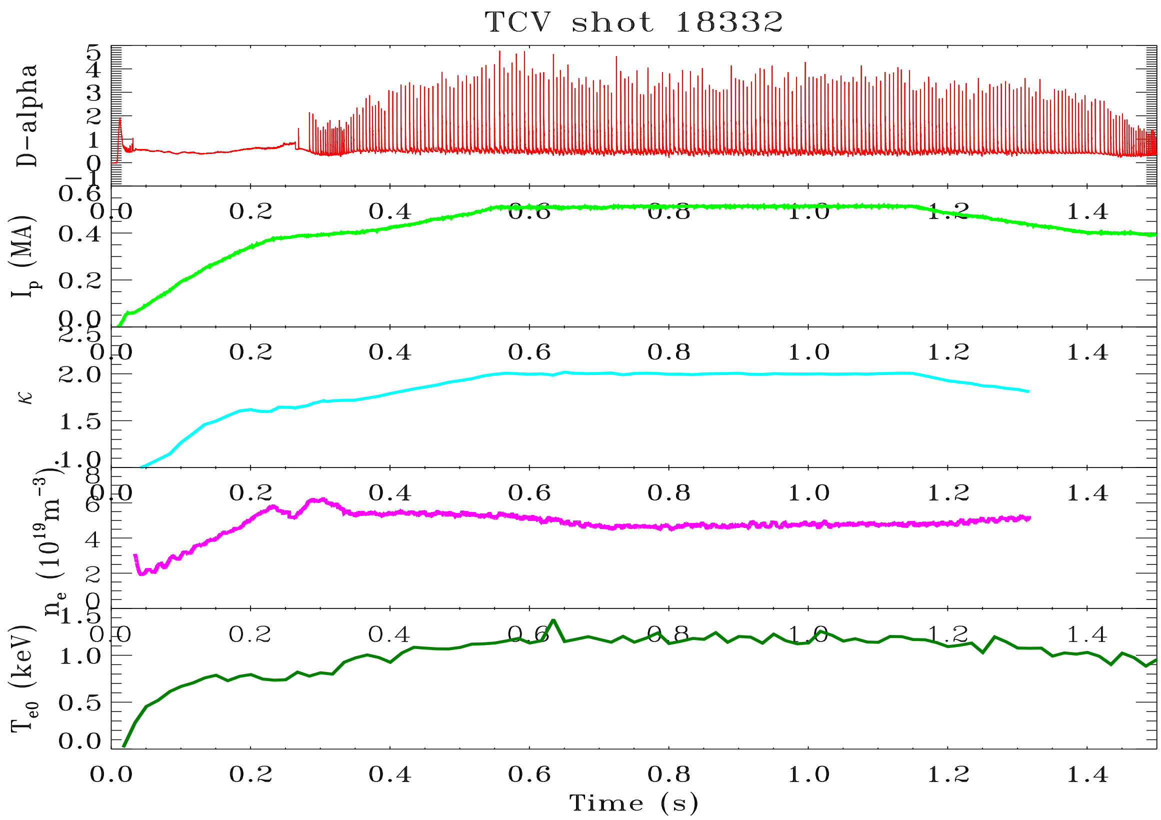

Fig.2: ELMy H-mode discharge in TCV, showing (top to bottom) D-alpha light, plasma current, elongation, line average electron density and electron temperature on axis.

2. Perturbation of the Vertical Position Control System by ELMs

TCV has a unique vertical position control system using active feedback coils both outside and inside the vacuum vessel [2]. The external coils (F-coils in Fig.1.) are driven by slow power supplies with a response time of ~1 ms, whereas the internal coils (G-coils) are driven by a fast supply with a response time of less that 0.1ms. The F-coils are used for proportional and derivative feedback and the G-coils are used exclusively for derivative feedback. The system allows the stabilization of elongated plasmas with very high growth rates and extremely low stability margins [2].

Steady-state ELMy H-mode plasmas are produced routinely in TCV [3]. Here, we consider an Ohmic, single-null divertor discharge (Figs.1 and 2), whose ion grad B drift is in the unfavourable direction, i.e. away from the X-point. Magnetic perturbations produced by ELMs can be seen mainly in the fast control loop. This loop uses a vertical position observer consisting of a linear combination of magnetic field probe signals. The probes are installed inside the vacuum vessel in several poloidal planes [4]. For vertical position control, we use the average signals of two poloidal arrays which are displaced toroidally by 180^0. The probes measure the poloidal field parallel to the vessel wall. They are distributed uniformly over the poloidal circumference and they are numbered clockwise, from 1 to 38, starting from the inboard midplane. The coefficients which are used to construct the vertical position signal are shown in Fig.3a. Note that probes 13-16 and 24-27 are not used in this observer, i.e. their coefficients are zero. This choice is motivated by the fact that these probes are located in the vicinity of the internal active coils (G1, G2) and that we wish to avoid direct coupling between the active coils and the observer.

The effect of ELMs on the observer output and hence, on the G-coil voltage, is seen in Fig.4b. Each ELM produces a perturbation of the vertical velocity signal lasting for approximately 1ms. The perturbation is significant but, in this case, it does not lead to saturation of power supply voltages or currents and hence the plasma survives.

3. ELM and VDE Signatures

Figure 3b. shows the poloidal field perturbation produced by a typical ELM. Here, we plot the poloidal field difference between the time when the ELM perturbation reaches its maximum and the time immediately preceeding the ELM. The measurement was performed under closed loop conditions. As a result, we see both the signature of the ELM and the effect of the current pulse in the internal active coil (peaks at #14 and #26). The ELM signature can be compared with a typical VDE signature. Figure 3c. shows poloidal field measurements during a VDE which was induced by a feedback cut. We note that VDE and ELM signatures are quite different and this difference can be exploited for the construction of an ELM-resistant observer.

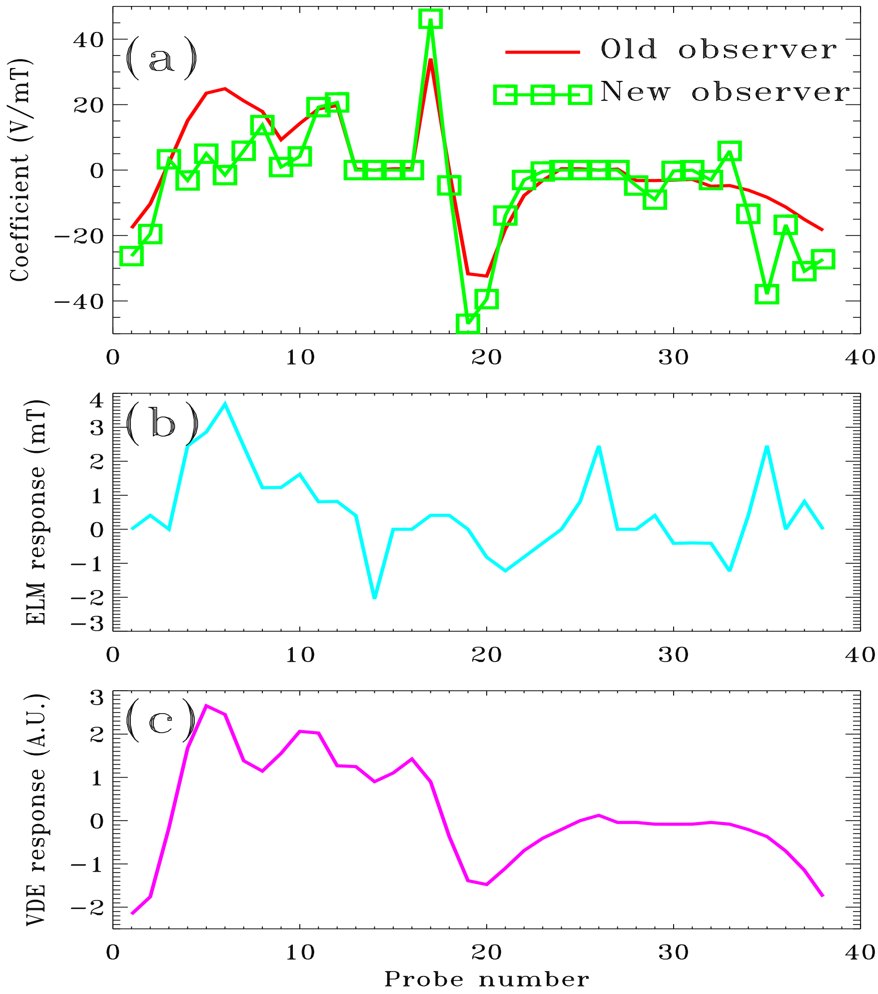

Fig.3.: (a) Old and new observer coefficients vs. probe number, (b) ELM response (Shot 18329 at 0.76s), including effect of internal active coils (peaks at #14 and #26), (c) Response of a VDE (Shot 15971 at 0.605 s). The VDE was intentionally produced by a preprogrammed feedback cut.

4. New Observer

Using the measurements presented above, we can now proceed to the construction of a new observer which satisfies the following four constraints: (1) the new observer coefficients must be orthogonal to the fast ELM response, (2) the new observer must give the same response to a rigid vertical displacement of the plasma as did the old observer, (3) the coefficients 13-16 and 24-27 must be zero to avoid coupling with the active coil and (4) the difference between the new and old observer coefficients should be minimized in the least squares sense. The result of this optimization procedure (Fig.3a.) shows that a minor modification of the observer coefficients is sufficient for satisfying the constraints mentioned above.

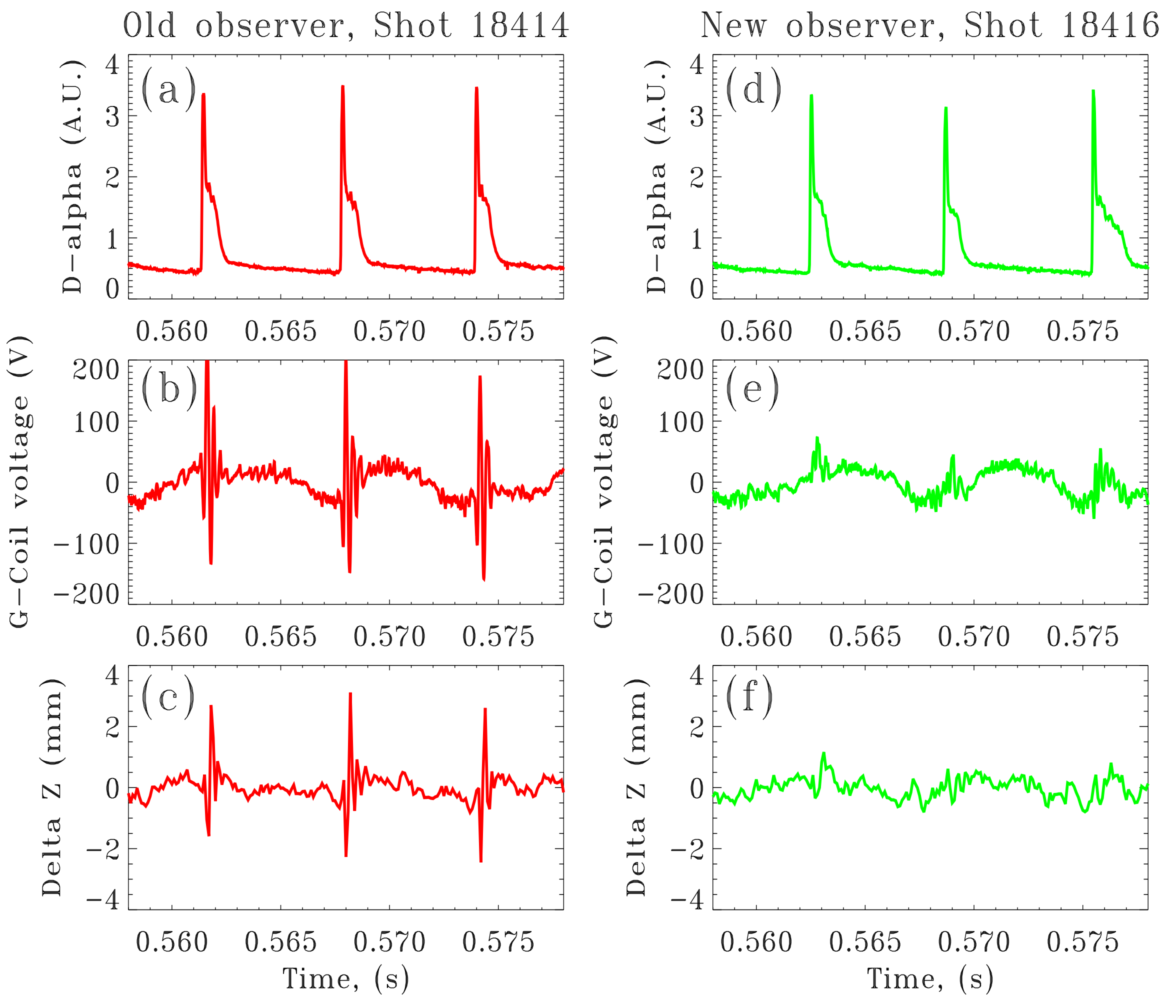

Fig.4.: (a) and (d): D-alpha signals of two identical ELMy H-mode discharges in TCV: (b) and (e): G-coil voltage, proportional to vertical plasma velocity, as obtained from old and new observers. (c) and (f): Vertical plasma displacement as obtained from LIUQE equilibrium reconstructions at 10 kHz sampling rate.

The new observer was tested in TCV by applying it to a typical steady-state ELMy H-mode plasma (Fig.2.). This plasma has relatively high elongation (κ=2) and, consequently, a high vertical instability growth rate (γ=1300 s^{-1}). ELM effects of the new and old observers are compared in Fig.4. It is seen that the new observer reduces the voltage pulses in the fast control loop by at least a factor of 5 (Figs. 4b and 4e). In addition, the vertical position excursion produced by each ELM is reduced by more than a factor of 3 (Figs. 4c and 4f). From these results we conclude that the perturbations produced by ELMs in the TCV vertical position control system can be significantly reduced by using an optimized vertical position observer.

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