ELM control using vertical kicks on the COMPASS tokamak

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Introduction

The H-mode is a reference scenario for the ITER operation, however, the ELMs may cause unacceptable power loads to the plasma facing components. Therefore, several ELM control mechanisms are studied: resonant magnetic perturbations, pellet injection, and magnetic pacing by fast vertical movement of the plasma column (called “vertical kicks”) [1].

In this paper we focus on the vertical kicks which were studied at several devices recently, incl. JET. The vertical kicks are considered as an option for the ELM control using the existing coils in ITER during the current ramp up/down (at plasma current $I_{pl} < 10$ MA) [2,3].

The COMPASS tokamak (R = 0.56 m, a = 0.2 m, $I_{pl} < 400$ kA, $B_T = 0.8$-1.5 T) achieves both ohmic as well as NBI assisted H-mode discharges [4]. Type III ELMs, ELM free periods, and type I ELMs are obtained. In the first experiments reported here, the plasma was destabilized by a short pulse (800 V) to the vertical position control coils in order to move the plasma column quickly and then the plasma control was recovered.

Experimental set-up

In standard experiments, the vertical position of the plasma is controlled by a Fast Amplifier for radial magnetic field (FABR, 100 V, 5 kA, switching frequency 40 kHz), based on MOSFET transistors. However, another power supply is required to induce the fast movements of the plasma column – the vertical kicks. For this purpose, the Vertical Kicks Power Supply (VKPS, up to 1.2 kV, 5 kA, switching frequency < 5 kHz) was designed, constructed, and connected in series with the FABR. The VKPS is capable of achieving current changes $dI_{BR}/dt \approx 8$ kA/ms in the vertical position control circuits, which is 8 times more than the FABR only [5]. A capacitor bank (4 x 4.14 mF, 2.53 kV) stores the energy to feed the VKPS for several dozens of 100 – 250 μs pulses of 1-2 kA.

In the experiments on COMPASS, the plasma is typically moved by VKPS pulses of 800 V with duration of approximately 100 μs each, applied to the vertical position control coils. Such pulses cause typically current change $\Delta I_{BR} \approx 1$ kA and vertical displacement $\Delta z \approx 1$ cm in less than 0.5 ms.

Reaction of feedback control

The VKPS pulse to the control coils destabilizes the plasma and the velocity of the plasma centre dz/dt may reach up to approximately 30 mm/ms. The FABR itself can assure maximum current change $|dI_{BR}/dt| = 1$ kA/ms, when operating close to the $I_{BR} = 0$ kA. The stabilizing magnetic field created by the feedback coils is 2.0 mT/kA in the plasma centre and 3.5 mT/kA at the top and bottom of the plasma which is closer to to coils [6]. However, this reaction is not strong and fast enough to recover the plasma control.

Therefore, a reversed VKPS pulse must be applied to bring the plasma back to the operational space of the FABR. An example of still non-stabilized vertical kick in Fig. 1 demonstrates the reactions of the FABR and VKPS power supplies during and after the vertical kick. The red lines in the upper panel highlight the action of the two power supplies, reaching current change of approximately $|dI_{BR}/dt| \approx 7\text{-}9$ kA/ms (at $I_{BR} \approx -1$ kA) in the control coils; the orange line shows the maximum capability of FABR current change is approximately $|dI_{BR}/dt| \approx 0.5$ kA/ms (at $I_{BR} \approx -1.5$ kA). These results are well in line with the modelling predictions for COMPASS circuits [6] at $I_{BR} = 0$ kA: $|dI_{BR}/dt| = 8$ kA/ms (VKPS+FABR) and $|dI_{BR}/dt| = 1$ kA/ms (FABR only).

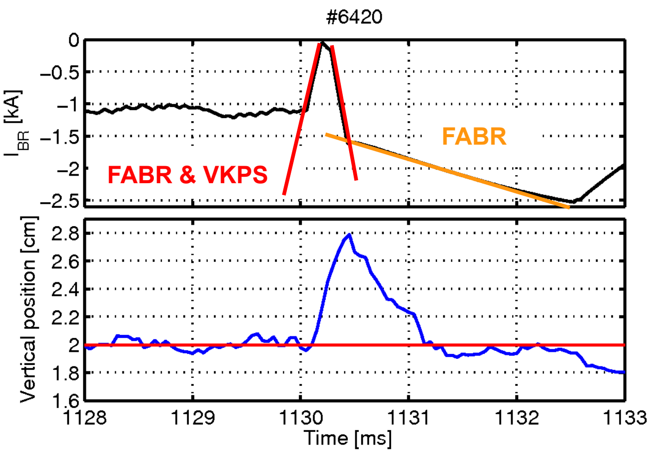

Figure 1: *Time evolution of the current to the vertical position control coils I_{BR} (top panel) and the corresponding vertical position (bottom panel) derived from magnetic measurements during a fast movement of the plasma column at 1130 ms.*

The bottom panel in Fig. 1 shows the induced vertical displacement of the plasma column which follows the current pulse to the control coils and reaches approximately +8 mm.

Stabilization of vertical kicks

Figure 2 shows an ohmic discharge with vertical kick applied and stabilized during a steady state phase of the discharge. It was found that such instability induced externally by the VKPS pulse of 100 μs / 1 kA can be stabilized by a reversed VKPS pulse (typically ~2x longer, with ~2x higher amplitude of the current change) and then by the standard feedback control with FABR. The reversed VKPS pulse brings the plasma back to the space where the z and dz/dt can be stabilized by the FABR within its operational limits.

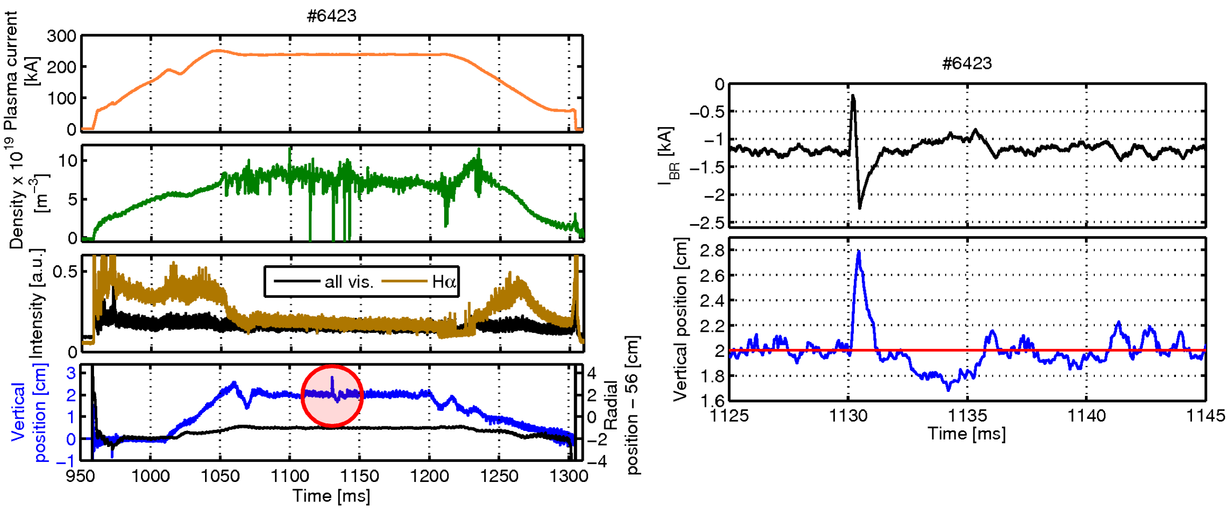

Figure 2: *a) Time evolution of the plasma current, plasma density, intensity of the* H_α *line emission and of the integrated visible light, and vertical and radial plasma positions in a discharge with a single vertical kick (marked by red circle) in the steady-state phase of the discharge at t = 1130 ms. b) Current to the vertical position control coils* I_{BR} *and the corresponding vertical position z during the vertical kick.*

Vertical kicks in ELM free H-mode

A set of experiments with vertical kicks was done in the ELM free phases of H-mode discharges recently. We were able to displace the plasma column by 8-13 mm and to recover the position control repeatedly. In Figure 3, four consequent kicks are shown in the left panel. After the first kick, we can observe an externally induced ELM, with lower and wider peak of the intensity of the H_α emission than the next "natural" ELM. Moreover, the natural ELM is registered by the vertical position derived from the magnetic diagnostics measurements [7].

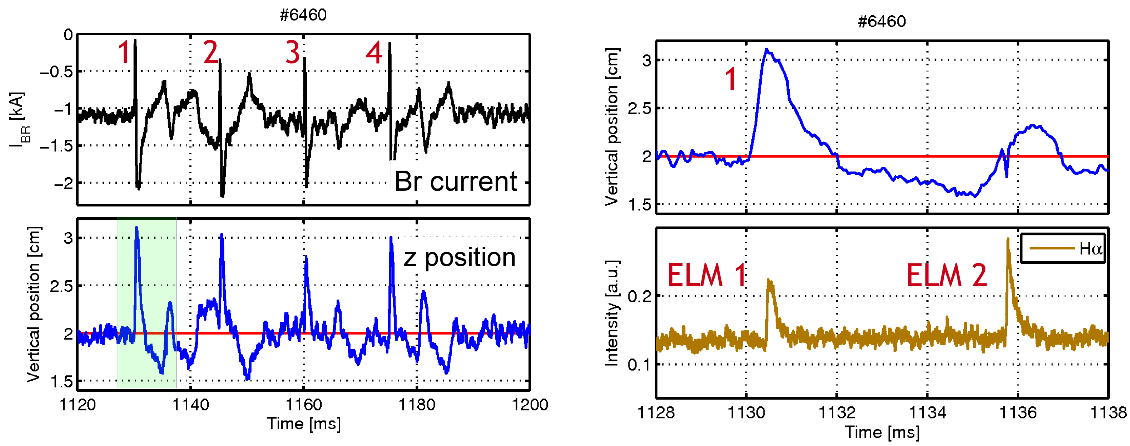

Figure 3: a) *current to the vertical position control coils I_{BR} and the corresponding vertical position z during several consequent vertical kicks. b) detail of the z position and H_α intensity showing two ELMs*

Summary

A dedicated power supply for fast movement of the plasma column, the VKPS was designed, built, and commissioned at the COMPASS tokamak. The first experiments show that the plasma can be repeatedly displaced by approximately 1 cm and stabilized again. The possibility to induce the fast vertical movements of the plasma column up to $\Delta z/R \approx 1.3 - 2.3$ and to stabilize it again was proved in ohmic discharges as well as in H-mode discharges. Moreover, experiments with several consequent vertical kicks were performed in the H-mode discharges. In ELM-free H-mode periods, ELMs linked to the VKPS pulses were observed and the results indicate different behaviour of the ELMs linked to the vertical kicks and of the natural ELMs.

Acknowledgements

The work was supported by Czech Science Foundation grant P205/11/2470 and by project MSMT LM2011021.

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