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Design of an advanced stabilizing shape controller on TCV using a rapid free-boundary simulator

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Shape control of the plasma in a tokamak is instrumental for experiments that require accurate shaping such as e.g. negative triangularity, double null or advanced divertor configurations. TCV with its high number of independently controlled PF coils and its elongated vessel allows for a large variety of scenarios posing an ideal test environment for shape control. Most currently implemented shape control schemes, as well as the shape controller envisioned for ITER, feature a distinct timescale separation between the slow shape control (~10Hz) and the fast plasma position controller (~1kHz) [1, 3]. A controller which handles both shaping and vertical stabilization, i.e. a stabilizing shape controller could achieve faster settling times while simplifying the overall controller architecture. In contrary to larger machines like ITER and JT-60SA, TCV with its high vertical growth rates represents a much greater challenge for stabilizing shape control. Apart from shape observers fast enough to support a control architecture at above 1kHz and which are suitable for the variety of plasmas at TCV, an accurate description of the plasma equilibrium evolution and a linearized model are required to effectively design and tune such a controller.

To this end, we employ FGE, a fast and control-oriented Grad-Shafranov equilibrium evolution solver that is part of the MEQ suite of codes [4], which also provides codes for equilibrium reconstruction (LIUQE) and for solving the inverse optimization problem for shot preparation (FBT). It provides the means to quickly simulate controllers in the loop and compute linearizations of the plasma evolution dynamics around a fixed equilibrium, making it an ideal platform for controller development. In this talk, we demonstrate the use of FGE in designing and validating a stabilizing shape controller for TCV where we make use of fast shape observers computed using a finite element approximation of the plasma current density [2]. While this approach will be primarily tailored to TCV, we emphasize that the presented design principles directly carry over to other machines.

References

[1] Anand *et al*, Nuclear Fusion 57, 126026 (2017)
[2] Hofmann *et al*, Nuclear Fusion 28, 519 (1988)
[3] Mele *et al*, PPCF 67, 65035 (2025)
[4] Merle *et al*, to be submitted.