Towards model-based control of divertor detachment

Towards model-based control of divertor detachment

J.T.W. Koenders[1,2]
[1] Energy Systems and Control Group, DIFFER, Eindhoven, the Netherlands
[2] Control Systems Technology Group, Eindhoven University of Technology, Eindhoven, the Netherlands
J.T.W.Koenders@differ.nl

1 Introduction

The heat and particle exhaust in tokamaks, the leading reactor design for economically viable clean energy production through thermonuclear fusion, is guided to a dedicated region called the divertor. Here, the plasma interacts with the divertor surface material causing erosion and hence impurities to enter the plasma. Unmitigated, the expected power fluxes impacting the divertor target during reactor operations exceed present-day engineering limits [1]. Real-time feedback control of plasma detachment, a regime characterized by a large reduction of plasma temperature and pressure at the divertor target, is required to obtain and maintain low target fluxes. A systematic approach to achieve this reduction was recently developed and experimentally demonstrated [2] on the Tokamak à Configuration Variable (TCV) at the EPFL [3]. This approach uses dedicated system identification experiments for controller design enabling control of the CIII emission front position, which is related to a relatively low temperature (<10 eV) region along the divertor leg [4]. We aid controller design by investigating the system identification results and extracting a dominant physical process. This is the first step to obtain a scalable control-oriented model of the CIII emission front position based on physical parameters.

2 Method

The control problem can be reduced to an input: fueling of deuterium molecules by a gas valve Γ_{puff} [#/s], and an output: the CIII emission front location L_{pol} [m]. Real-time (800 Hz) tracking of the CIII emission front was implemented using a detection algorithm [5] applied to spectrally filtered images originating from the multi-spectral imaging diagnostic MANTIS [6]. Figure 1 shows the MANTIS camera view, a visual representation of the detection algorithm and the definition of the parameter L_{pol}. The gas valve is located at the bottom of the machine. System identification experiments were performed by injection of a multisine perturbation on the input Γ_{puff} and measuring L_{pol}. Due to the low signal to noise ratio environment it was chosen to excite three to six frequencies per experiment. Additionally the gas valve system limits the frequencies to <50 Hz. Extraction of a physical process was done by fitting first-principle physics models on the obtained FRF measurements. Steady-state behavior of the system was estimated using the established time-independent equilibrium code SOLPS-ITER.

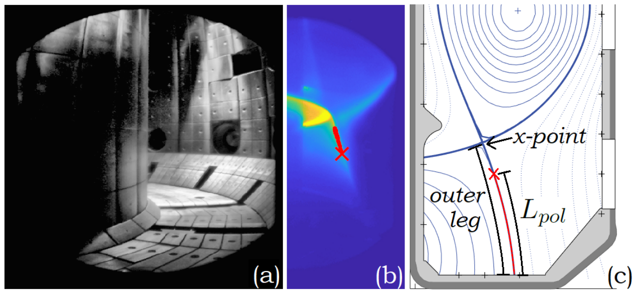

Figure 1: (a) MANTIS camera view in the TCV Tokamak [6]. (b) Identified CIII front location by the detection algorithm, indicated by the red X [5]. (c) Geometric representation of the front location L_{pol} along the outer leg.

3 Results and Discussion

The identification experiments show phase behavior reminiscent of a diffusive system, we find a 1D diffusion dominated transport model to accurately describe the obtained FRF measurements. We present a novel control-oriented grey-box model describing the dynamics of input Γ_{puff} to output L_{pol}. The model accurately reproduces experimental observations and can be used for controller design within the identified operating regime.
The underlying physics responsible for the diffusive like behavior is to be investigated, we hypothesize the process is dominated by plasma-neutral interactions the injected deuterium molecules undergo until they are ionised.

4 Acknowledgments

The author thanks Marco de Baar, Matthijs van Berkel, Basil Duval, Olivier Février, Cristian Galperti, Ricky van Kampen, Artur Perek, Timo Ravensbergen, Christian Theiler, the TCV Team, and the EUROfusion MST1 team.

References

[1] R. Pitts et al., Nucl. Mat. Ener. **20**, (2019)
[2] T. Ravensbergen et al., Nat. Commun. **12**, (2021)
[3] S. Coda et al., Nucl. Fusion **59**, (2019)
[4] C. Theiler et al., Nucl. Fusion **57**, (2017)
[5] T. Ravensbergen et al., Nucl. Fusion **60**, (2020)
[6] A. Perek et al., Rev. Sci. Instrum. **90**, (2019)