Review of the habilitation thesis by Dr Radomír Pánek "Study of peripheral plasma in the COMPASS tokamak"

The thesis deals with the study of peripheral plasma in the COMPASS tokamak based at the Institute of Plasma Physics, Czech Academy of Sciences, Prague. The text is logically organised into 4 chapters: "Introduction to fusion", "Confinement of plasma in tokamaks", "Characterisation of H-modes in the COMPASS tokamak" and "Conclusions and perspectives".

The first chapter introduces into fusion energy and its realisation in tokamaks. The text is well written and gives balanced overview of advantages and challenges of tokamak approach. The chapter concludes with assessment of access window to H-mode and performance of this particular confinement regime. It is rightly stated in the thesis that the predictions to next step tokamak ITER are mainly based on empirical scalings which are subject of considerable uncertainty. However, it has to be noted that there is also growing experimental evidence that the access window and quality of H-mode can be influenced by number of externally controllable factors such as geometry of heat and particle exhaust systems, by choice of material of plasma facing surfaces, and geometry and type of plasma fuelling. All these dependences could be exploited and optimised in order to improve plasma performance in future tokamak ractors.

Sections 2.1 and 2.2 describe plasma confinement. Again the text is well balanced and provides smooth efficient journey through this vast topic. It rightly describes L-mode to H-mode transition as central to the application of tokamaks as fusion energy source. Author correctly introduces empirical scalings for energy confinement times as a key tool for assessment of quality of today's plasma and for prediction towards future devices. At this point it might be noted that despite a justified criticism of these empirical formulas, they were the only tool we had at the time of freezing the ITER's main design parameters. Second point worth to mention is that energy confinement scalings are not completely physics-free. When expressed in dimensionless parameters they show that the dependence on Larmor radius normalised to plasma size is different for L-mode and H-mode. More precisely L-mode shows weak (Bohm) dependence while H-mode shows stronger (gyro Bohm) dependence. Therefore the ratio of H-mode to L-mode energy confinement times is not constant and the value H ~2 refers roughly to JET size machines.This also demonstrates why H-mode provides more efficient regime for next step devices which will have smaller normalised Larmor radius compared to today's tokamaks

Section 2.3 introduces various states of the plasma edge and discusses them in terms of conventional density – temperature diagram. The transition between these plasma states is logically described and commented from the theory point of view. I can make only one comment here, namely regarding the L-H transition. It the thesis this transition is related to critical edge temperature, however, counter examples also exists where H-mode is induced by pellet injection such as in TUMAN-3 (Phys Fluid B 5 (1993)2420) , D3D (PRL 86 (2001) 644) and MAST (NF 52 (2012) 114022).

Sections 2.4, 2.5 and 2.6 are the overview of Edge Localised Modes (ELMs). Again this vast subject is nicely reviewed providing the phenomenology of key ELM types and their possible explanation by theory. The overview is completed by a paragraph on possible mechanism of ELM loss. Here the conventional description is given in terms of plasma filaments detached by reconnection from core plasma and moving radially towards the wall. It has to be noted that the physics mechanism of how the ELM related plasma crosses the separatrix is still not understood and nonlinear MHD simulations are often failing to describe the data. At this point I would prefer to include the section on ELM control techniques, perhaps instead of the section 2.7 on internal transport barriers as it is less subject of the thesis. This however is not a serious drawback as ELM control by RMP coils is mentioned later in the thesis.

Sections 3.1, 3.2 and 3.3 describe the COMPASS tokamak. Sections are again well written and they give the list of main plasma parameters, description of neutral beam heating and exhaustive list of plasma diagnostics. Section 3.1 is the first time where COMPASS load assembly is mentioned and therefore table 3.1 should also give the plasma size.

Section 3.4.1 describes the H-mode operation window in COMPASS. The section rightly notes that there is some minimum density for H-mode access and this might prevent ECR heating if frequency is low. For that reason at Culham fundamental resonance ECR heating was used with HFS launch for which the cut off density is well above the minimum value required for H-mode access. In this context one can note that eq 3.1 describes only high density branch of L-H threshold – at low density power required for L-H threshold exceeds this scaling. This low density branch could complicate the interpretation of L-H threshold in particular if Ohmic power is significant.

Section 3.4.2 describes ELM characteristics in COMPASS as revealed by high temporal and spatial resolution cameras and Langmuir probes. This section show several beautiful examples of ELMs structures, namely its filamentary character when the ELM event reaches the SOL. For record it was COMPASS-D where the "filamentary" ELM structure was reconstructed from Mirnov coils data (see figure 7 in ref [36]). Looking ahead, COMPASS with its impressive set of existing and planned diagnostics is well poised to document and understand the ELM event in ever more details. More importantly, with RMP coils, this can be studied in relevant regime of controlled or mitigated ELMs. In this context the detection of inter ELM structures as shown in figure 3.9 is very good start for further understanding and control of ELM events.

Section 3.5 describes quasi coherent modes in H-mode. These modes have Alfvenic dependence of frequency on density, rotate in electron diamagnetic drift direction and have poloidal mode numbers around 5 to 8. The ballooning part of these modes (50 - 150Hz) is identify as beta driven Alfven eigenmodes. It might be useful to look whether there is any connection between these modes and some of ELM precursors which would underline their relevance. The modes with similar characteristics were noticed on COMPASS-D and have been dubbed as incomplete ELMs (EPS 1994 Conference 18B, pp-III p318).

In conclusion, the whole thesis is well written. The review part is well balanced and captures the cornerstones of present understanding of the subject and clearly formulates the gaps in our knowledge. The results part is well presented and contains internationally competitive research as is documented by published COMPASS papers and presentations at conferences or meetings. Finally the chapter Conclusions and Perspectives summarises the thesis and sets clearly future directions of research on the COMPASS tokamak as a highly flexible tool for studies of relevant problems in tokamak science.

I recommend that the applicant, Dr Radomír Pánek, is appointed as an associate professor.

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