Characterization of Ohmic and NBI heated H-mode in the COMPASS tokamak

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1. Introduction

The COMPASS tokamak is a compact experimental device (R = 0.56 m, a = 0.2 m) operated in divertor plasma configuration with ITER-like plasma cross-section ([1], [2]). Presently, COMPASS operates with plasma current up to 250 kA and toroidal magnetic field in the range 0.9 – 1.8 T and elongation 1.8. Two neutral beam injectors provide power of 2 x 0.4 MW at the beam energy of 40 keV for additional plasma heating. Recently, an Ohmic as well as NBI assisted H-mode has been successfully achieved on the COMPASS tokamak after application of boronization of the vacuum vessel interior. The L-H transition is followed either by an ELM-free period or ELMs with frequency in the range of 150 – 1 000 Hz.

2. Experimental setup

The described experiments were performed at B_t = 1.2 T, I_p = 160 – 240 kA, plasma elongation 1.8 and triangularity 0.4 with the lower single-null divertor configuration (so called SNT) and the ion grad B drift direction towards the x-point. The NBI heating power delivered into the plasma was up to 320 kW.

Extensive wall conditioning methods were used to minimize the hydrogen inventory and impurity influx. Several-day baking of the vacuum vessel and plasma-facing components (PFC) at the temperature of 150 °C were followed by a boronization of the vacuum vessel by carborane vapors in Helium glow discharge (GDC) to optimize the wall conditioning and decrease the radiating power losses by impurities. In between shots a Helium GDC is performed. Deuterium plasma is fueled by a gas puff valve located below the outer midplane.

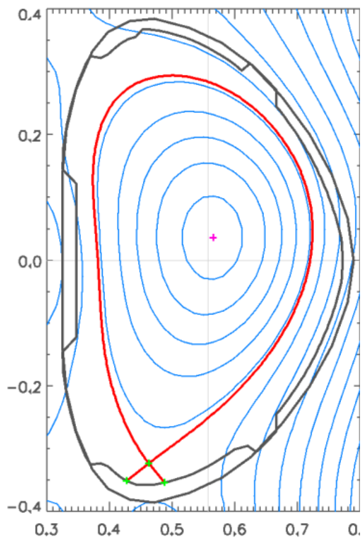

Fig. 1: Plasma cross-section in COMPASS (EFIT reconstruction).

The L-H transition is identified by a drop of D_α signal. In addition, the signal from the diamagnetic coils or the EFIT reconstruction is exploited to calculate the stored energy. The radial profiles of electron temperature and density were measured using the High resolution Thomson scattering system [2]. COMPASS is equipped by a complex of electric probes and arrays of SXR and bolometric sensors.

3. Experimental results

Ohmic H mode

The transition to the Ohmic H-mode is usually triggered by switch-off of the gas puff, followed by gradual decrease of the D_α signal as shown in the Fig 2. After the L-H transition at t = 1057 ms a short ELM-free period is seen followed by series of Type-III ELMs.

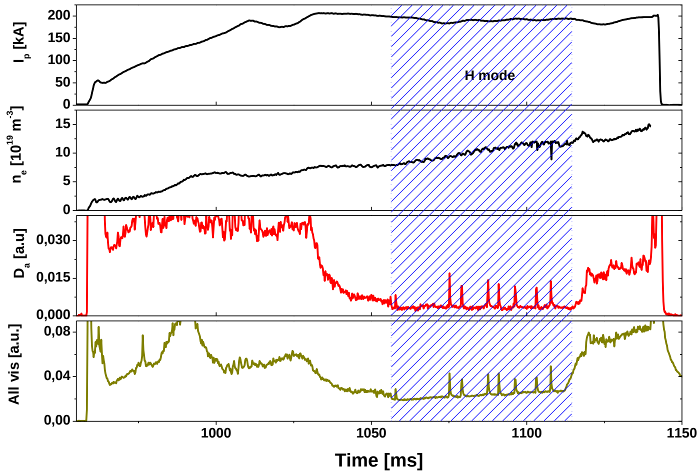

Fig. 2: Evolution of the discharge #4334. From top to bottom: plasma current, plasma density, D_a signal and visible radiation over the whole spectral range.

The total stored energy is almost constant at the level of W = 4.1 kJ during the H mode phase. The H mode phase is terminated by a smooth H-L transition at t = 1114 ms, which is caused by impurity accumulation. This feature is evident from the trace of the integral visible radiation, shown in the bottom panel in Fig. 2.

NBI-assisted H-mode

Temporal evolution of a discharge where the L-H transition is triggered by NBI is shown in Fig. 3. The flat-top plasma current is 190 kA and the elongation is 1.8. The gas puff is switched-off at t = 1070 ms and, simultaneously, a co-direction NBI puls is applied with the output power of the injector of 320 kW.

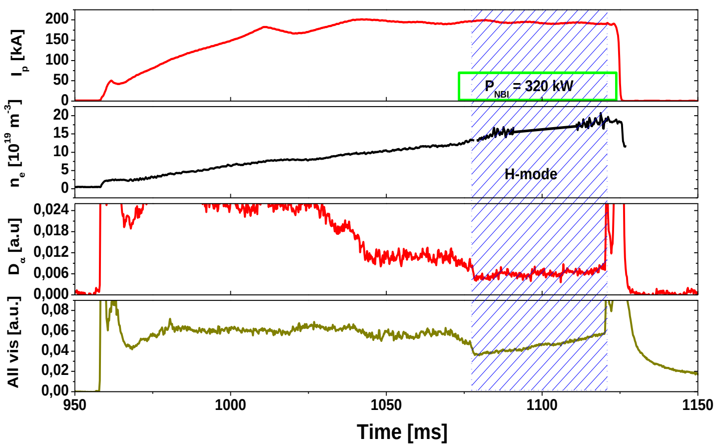

Fig. 3: Evolution of the discharge #4275. From top to bottom: plasma current, plasma density, D_a and visible radiation over the whole spectral range.

The transition to the H-mode is manifested by a fast drop of the D_α signal, which occurs spontaneously about 10 ms after beginning of the NBI heating. Afterwards, either Type-III ELMs or ELM-free periods (Fig. 3) are observed. In case of ELM-free period the discharge is usually terminated by a disruption caused by impurity accumulation (Fig. 3). A formation of the pedestal is confirmed by measurement of the radial profiles of the electron temperature and density by High Resolution Thomson scattering [3] shown in Fig. 4.

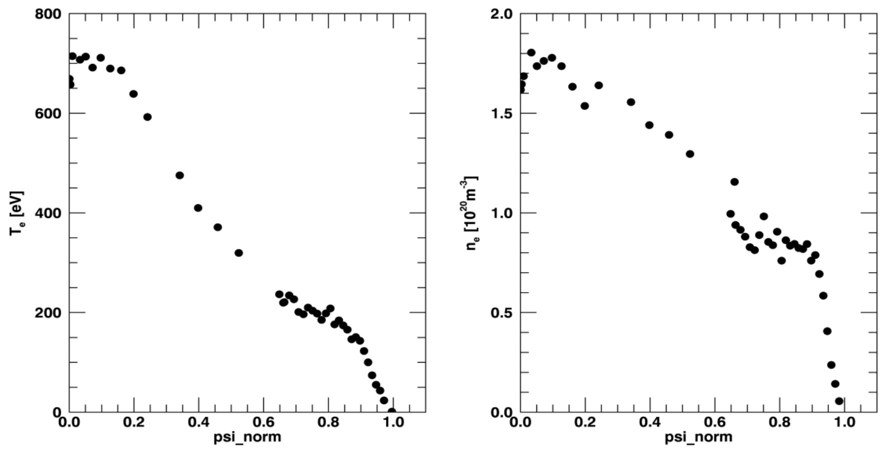

Fig 4. Radial profiles of the electron temperature and density in the H mode phase (t = 1113 ms) of the shot # 4275.

The central electron temperature reaches typically 0.7 - 1.3 keV, the central electron density is 1 - 2×10^{20} m^{-3}. The radial profile of the electron temperature is noticeably more peaked then the density profile. The pedestal profiles are fitted numerically by the tanh function [4] allowing the characterization of the pedestal parameters. The typical widths of the density and temperature pedestals are in the range of 1.9 - 2.3 cm. The height of the T_e pedestal reaches a value of 150 - 200 eV and the density pedestal height is (5 – 8) x 10^{19} m^{-3}. The pressure pedestal is narrower (approx. 1.3 cm) and its height is approximately 1.25 kPa.

The global energy confinement time is calculated as $\tau_E^* = W/(P_{OH} + P_{NBI})$, where the total stored energy W is estimated either from plasma diamagnetism or from the EFIT reconstruction. The absorbed NBI power is estimated to a half of the power at the injector output, as follows from numerical simulations [5]. Before L-H transition, the global energy confinement time is typically $\tau_E^* \sim 10$ ms, while it increases in H-mode by a factor of 1.8 – 2.0.

ELMs as seen by divertor probe array

The COMPASS tokamak is equipped by an array of 39 probes embedded in the divertor tiles. Probe No 1 is located at the HFS and the probe 39 is at the LFS of the divertor. The temporal evolution of a single ELM as seen by the divertor probes operated in I_{sat} mode is plotted in Fig.

5. The arrival of the ELM is manifested by a drop of the measured signal at t = 1144.37 ms, in particular on the probe #22. The drop, however, is probably caused by the decrease of the floating potential closer to the biased voltage. This perturbation propagates towards the HFS and it is followed by a few positive filaments, which appear at the HFS strike point and propagate through the SOL. The drop of floating potential can be due to the arrival of fast electrons from the plasma core, followed by the arrival of ions – seen as the positive filaments. Note also a similar propagation of I_{sat} minima, seen during the inter-ELM phase. These phenomena are not observed at the LFS strike point, where a peak of I_{sat} occurs and lasts until end of the ELM cycle.

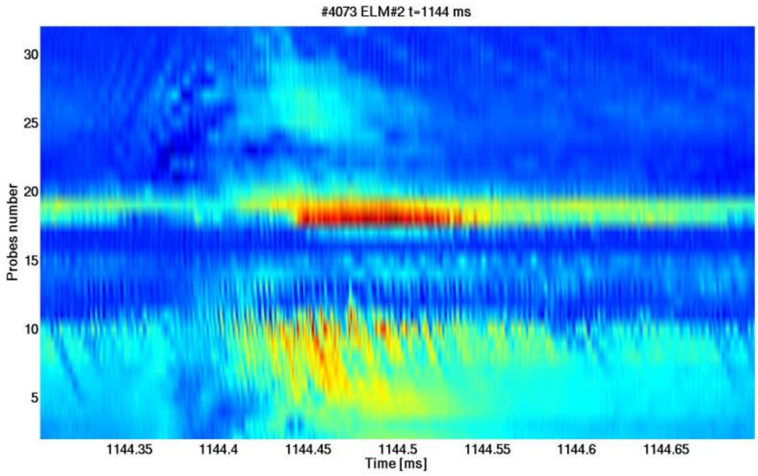

Fig. 5: Propagation of a single ELM across the divertor probe array for shot #4074. The strike points are localized close to the probes No. 9 and 19.

4. Summary

The paper provides a basic characterization of the Ohmic as well as NBI-assisted H-mode which have been achieved on the COMPASS tokamak recently. The first measurements of the pedestal profiles by HRTS system is presented including the estimate of energy confinement time increase by factor of two. The observation of Type-III ELMs by divertor probe array shows propagation of filaments on the HFS edge and SOL region. Detailed study of ELMs and pedestal is presently under way. An attempt to establish a scenario with Type-I ELMs is envisaged as soon as full NBI power becomes available.

Acknowledgement

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