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Properties of Filamentary Structures in Different Regimes of Plasma Confinement on the COMPASS Tokamak

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Abstract. A complex electrostatic-magnetic probe diagnostic, called U-probe, has been installed on the tokamak COMPASS recently. Probe composes of two identical towers. Each tower houses radialy separated 3 sets of 3D coils, a triple probe and a rake of six single Langmuir probes. We present measurements of electric and magnetic properties of the filamentary structures in the scrape off layer plasmas during different regimes of plasma confinement on COMPASS tokamak.

Introduction

Due to their characteristic shape, plasma structures elongated along the magnetic field lines are called plasma filaments. Filaments have increased density and temperature in comparison to the background plasma [*Spolaore et al.*, 2009; *Boedo et al.*, 2001] and moved radially outwards from the plasma column due to $\vec{E} \times \vec{B}$ forces. They are conducting electric current along them as was recently observed on RFX-mod and ASDEX-U [*Spolaore et al.*, 2009; *Martines et al.*, 2009]. Therefore, the filaments carry out energy from plasma and deposit it unequally on the walls of the vacuum vessel. Particularly, large groups of filaments are representing severe danger for the first wall and divertor components as well as inserted diagnostics and instrumentation [*Loarte et al.,* 2003].

This work presents the evolution of filamentary structures during L-mode and ELMy H-mode plasma confinement regimes on the COMPASS tokamak, particularly carried parallel current I_{par}, ion saturation current I_{sat} and floating potential V_{fl}. Properties were measured with U-probe, a part of complex diagnostics system for studies of the particle and energy transport as well as appearance, sustaining and disintegration of transport barrier in the edge plasma and scrape-off layer. Acquired knowledge will be used on analysis and mitigation of large and a potential danger for the first wall.

Plasma filaments

Important parameters of the plasma filament are transversal profiles of the electron density n_e, electron and ion temperature T_e and T_i, plasma potential Φ, vorticity ω, and the parallel electric current density j_{par}. In this work we will focus on the measured ion saturation current which is connected to the electron density and slightly affected by the temperature $I_{sat} \sim n_e\sqrt{T_e + \gamma T_i}$ and the floating potential which is proportional to plasma potential and electron temperature $V_{fl} = \Phi - \alpha T_e$. Coefficients α and γ are depending on the collector construction or the plasma heating respectively. Final recalculation to the basic plasma parameters is not performed because we had not measured all necessary parameters. Parallel electric current is calculated from signals of magnetic coils (blocks A3, B2 and B3 located in the rear part of the U-probe) using Ampere's integral:

$$\mu_0 I = \oint \vec{B} \times \vec{dl}\,.$$

Computed current density is denoted to the area enclosed by the used coil sets. Consequently, the final expression is:

$$I_{II} = \frac{1}{2\mu_0}\left(\frac{\left(B_{B3}^{rad} + B_{B2}^{rad}\right)\left(r_{B3} - r_{B2}\right) + \left(B_{A3}^{pol} + B_{B3}^{pol}\right)\left(p_{A3} - p_{A2}\right) +}{+\sqrt{\left(B_{B2}^{pol} + B_{A3}^{pol}\right)^2 + \left(B_{B2}^{rad} + B_{A3}^{rad}\right)^2}\;\sqrt{\left(p_{B2} - p_{A3}\right)^2 + \left(r_{B2} - r_{A3}\right)^2}}\right),$$

where p_i and r_i represents poloidal and radial coordinate of the i-th coil set.

U-probe

The U-probe consists of two identical towers made of boron nitride and housing a triplet of Langmuir tips at the top of the tower, an array of 6 Langmuir tips (rake probe) at the poloidaly oriented wall of the tower and 3 sets of 3D coils each. The rake probe has a space resolution of 4 mm in radial direction and covers a distance of 20 mm. The coil systems have resolution of 9 mm in radial direction and cover 18 mm. The poloidal space resolution of all systems is given by the axial distance of the towers which is 40 mm. This strongly affects calculation of the parallel electric current via the spatial derivative of magnetic field. The probe is inserted in the tokamak scrape-off layer close to the separatrix (from approximately 20mm from separatrix in dependence on position setting, plasma shape and position). The U-probe is mounted at a manipulator allowing for radial and angular adjustment on a shot-to-shot base at the outer side of the COMPASS tokamak below the midplane [*Kovarik et al.,* 2011].

L-mode discharges have no transport barrier and consequently no steep plasma pressure gradient. This is followed by steady and quasi uniform outflow of filaments which individually do not carry so much energy. Therefore they are not harmful, but represent constant energy and particle flow out of the confinement region.

L-mode vs. H-mode

H-mode is a special regime of plasma confinement where a transport barrier is formed at the edge of the plasma column. This barrier limits energy and particle outflow from the central plasma and consequently leads to an increase of density and temperature in the central plasma and creation of so-called pedestal, see Fig. 2. When a certain threshold of plasma pressure gradient within the transport barrier is exceeded, the pedestal collapse partially and a part of the hot dense plasma is released to the vacuum chamber walls. These structures of very hot, dense plasma (ELMs) have enough energy to damage diagnostics in the SOL or the first wall and divertor in case of larger fusion devices.

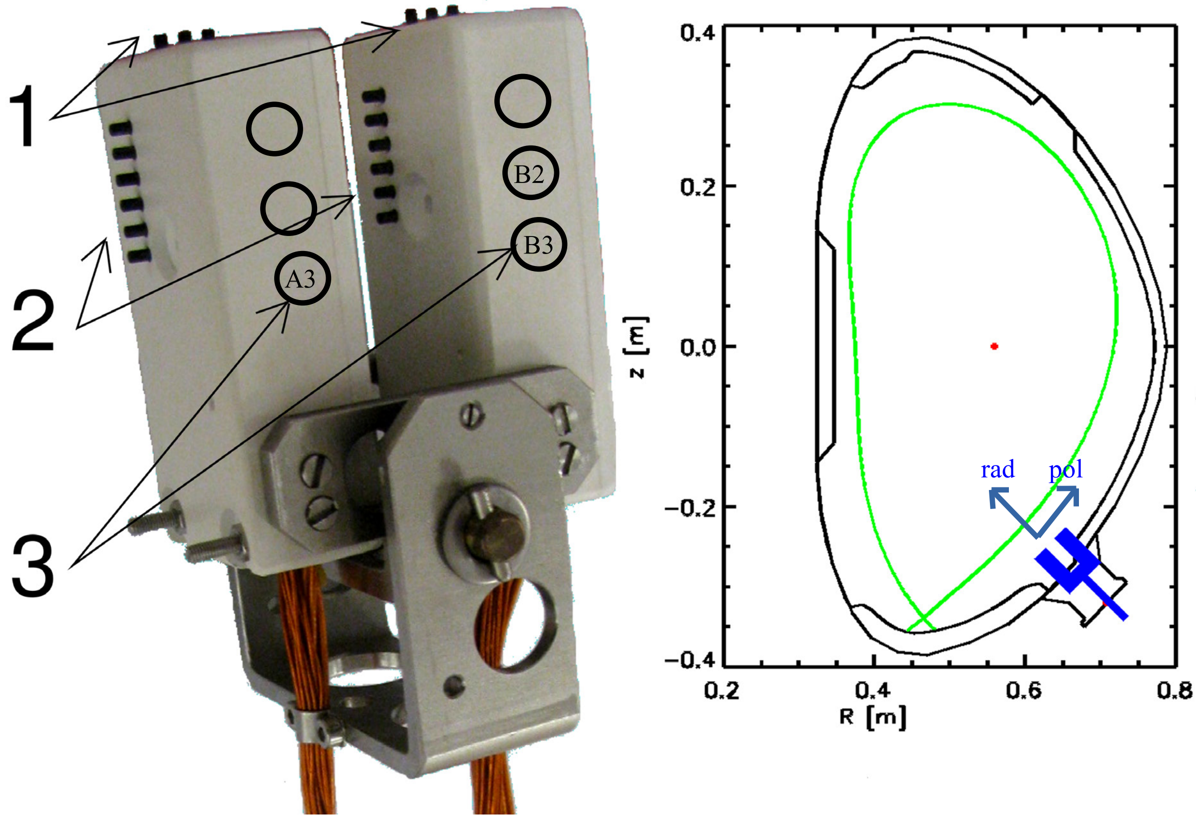

Figure 1. Left — Photographs of the U-probe (1—Triple probes, 2—rake probes, 3—coil sets hidden inside the probe head), right — schematic drawing of U-probe (blue) position inside the COMPASS tokamak with signed poloidal and radial direction (green line represents separatrix during the flat-top phase).

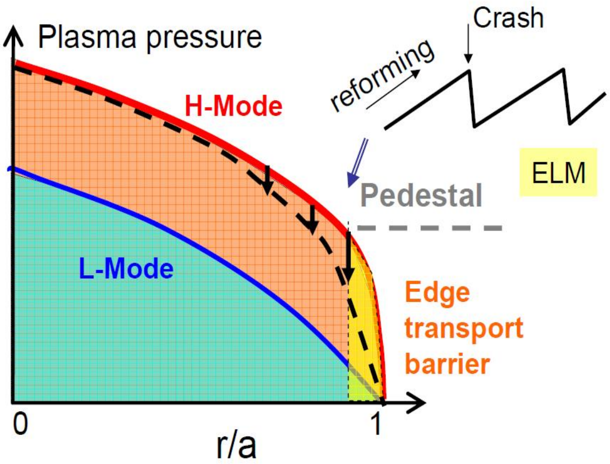

Figure 2. Schematic drawing of the H-mode regime and ELM creation.

Table 1. Basic parameters of the flat-top phase during discharge #7157.

Toroidal magnetic field B_T	1.15 T
Plasma current I_{pl}	300 kA
Density n_e	6×10^{19} m^{-3}
q_{95}	2.68

We compare L-mode filaments and ELMs in H-mode during the flat-top phase of discharge #7157. Basic plasma parameters of the discharge are given in Tab. 1.

Comparing of turbulent filamentary structures during two different phases of the discharge is shown in Fig. 3. The D_α radiation is used to distinguish the L-mode and H-mode as a result interaction of the neutral gas close the walls with the energetic particles escaping from the plasma column.. Moreover, it highlights the presence of the ELM.

The second graphs from top show parallel electric current calculated by Ampere's Integral. The left side clearly shows that effect of the L-mode filaments on the parallel electric current I_{par} is approximately in the range of 5 A with respect to the long-time evolution (red line). On the other hand, the change of parallel electric current within the ELM is clearly visible, in order of 15 A. The high ratio of current flows in the L-mode filament and ELM fulfill intuitive assumption that the turbulent structures are released from the plasma column and as the blobs are released more frequently than ELMs, the blobs will carry out less plasma including the carried fraction of plasma current.

The third graphs compare the evolution of the ion saturation current I_{sat} at different radial positions. It is clearly visible, that the L-mode filaments are medium sized structures occurring frequently, peak values are typically in order 0.2–0.3 A with a repetition rate in the order of 10 kHz. On the other hand, the ELM has a structure suggesting that an ELM is the combination of multiple more dense filaments flowing close together out of the plasma column, typical peak values of ion saturation current are in order of 0.7 A and the repetition rate of the ELMs is in order of 1 kHz. Between individual ELMs we measure very low ion saturation current which correspond to very low density in the SOL. Moreover, we observe a higher correlation between I_{sat} signals in the ELM (0.72) in comparison to L-mode filament. This fact can be simultaneously caused by two different ways. At first, the ELM is much larger than the L-mode filament, and second, the L-mode filament passed the tower B (the bottom one) only and was measured only by the edge-most Langmuir tip.

The bottom graphs show the evolution of the floating potential V_{fl} at several radial positions. There is apparent a low perturbation of the V_{fl} measurement during the L-mode in comparison to ELM filaments. This denotes lower perturbations in the plasma potential and the electron temperature. The strong drop of the floating potential during the ELM is caused by a high electron temperature.

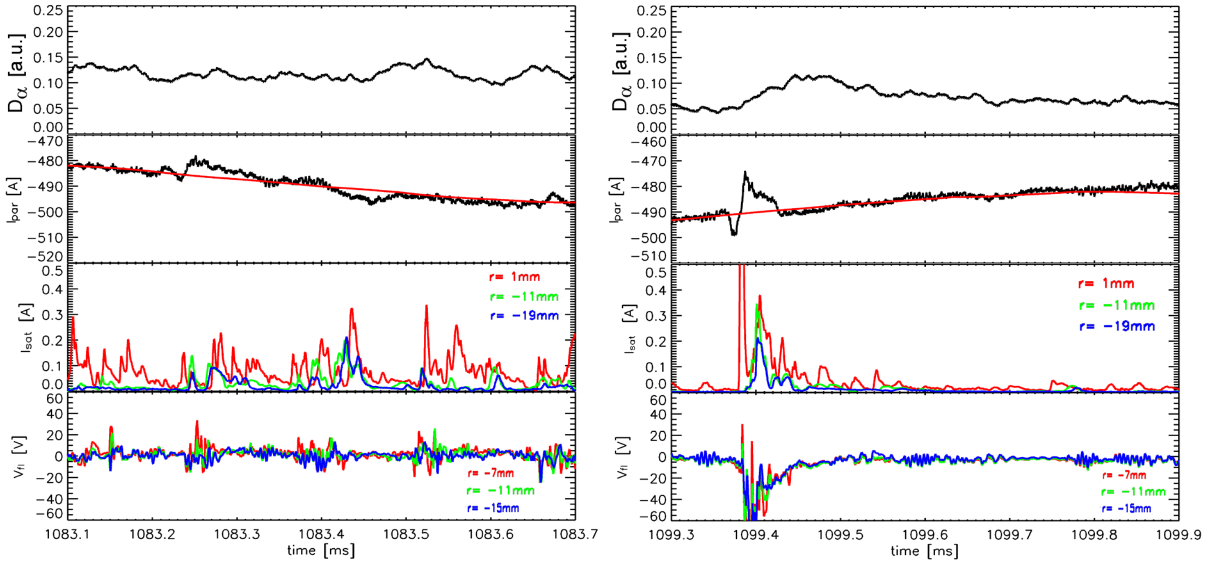

Figure 3. Temporal evolution of (from top to bottom) D_α radiation, parallel electric current I_{par}, Ion saturation current I_{sat} at different radii, and Floating potential V_{fl} at different radii during the L-mode (left) and ELM (right).

Correlation between the V_{fl} signals within the L-mode filament seems to be lower than in case of ELM crashes as observed in case of I_{sat} measurement, particularly as the graphs are plotted in the same ranges for better comparability. The explanation can be similar as in case of difference in I_{sat} signals correlation.

Summary

We confirmed higher parallel electric currents in the ELMs in comparison to L-mode filaments as expected. The temporal evolutions of floating potential and ion saturation current suggest high electron density and temperature of the plasma in the ELM filaments in comparison to L-mode filaments as expected.

Electrostatic signals during ELM show clearly internal structure of the ELM as a composition of multiple filaments as formerly observed on other fusion devices [*Kirk et al.,* 2005; *Boedo et al.,* 2005].

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