First Measurements with U-probe on the COMPASS Tokamak

K. Kovařík,[1,2] I. Ďuran,[1] J. Stöckel,[1] J.Seidl,[1,2] D. Šesták,[1] J. Brotánková,[3]
M. Spolaore,[4] E. Martines,[4] N. Vianello[4]
[1] Institute of Plasma Physics AS CR v.v.i., Association EURATOM/IPP.CR, Prague, Czech Republic.
[2] Charles University in Prague, Faculty of Mathematics and Physics, Prague, Czech Republic.
[3] Czech University on Live Sciences, Prague, Czech Republic.
[4] Consorzio RFX, Associazione EURATOM-ENEA sulla fusione, Padova, Italy.

Abstract. A complex electrostatic-magnetic probe diagnostics, baptized as 'U-probe', has been installed on COMPASS tokamak recently. Probe composes of two identical towers. Each tower houses 3 radially spaced sets of 3D coils, triple probe and rake probe — array of six Langmuir probes. The U-probe measures electric and magnetic properties of the filamentary structures in the edge plasma, particularly the floating potential profile and local magnetic field within the plasma filaments. Contribution presents first tests and results obtained.

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 rest of the edge plasma [1]. They are conducting electric current along them as was recently observed on RFX-mod [2, 3]. Therefore, the filaments take 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.

This work describes first results of the new probe diagnostics, the so-called U-probe, see Figure 1, on the COMPASS tokamak. It is a part of complex diagnostics system for studies of the particle and energy transport as well as appearance, sustainment and disintegration of transport barrier in the edge plasma according to properties of plasma structures in scrape-off layer (SOL). Acquired knowledge will be used on analysis and mitigation of large and potentially dangerous filamentary structures mentioned above.

U-probe design

The U-probe is designed to measure electric and magnetic properties of the plasma filaments, particularly profiles of floating potential V_{float} and magnetic field $\boldsymbol{B}$. Radial profiles of vorticity $\boldsymbol{\omega}$ and parallel electric current $j_{//}$ flowing through the filaments are determined using these measurements.

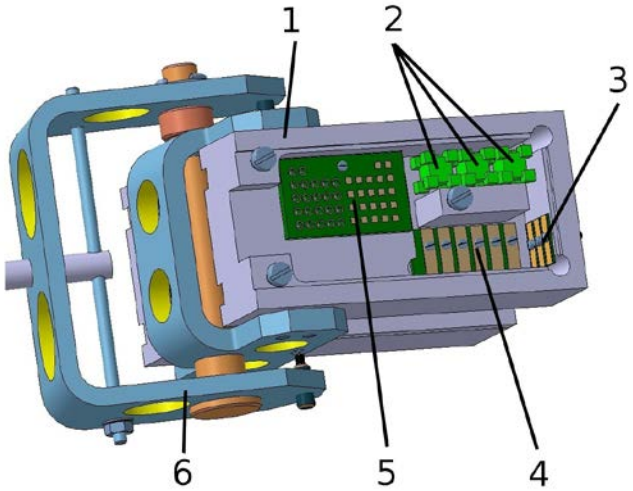

Figure 1. Design drawing of one tower of the U-probe. 1 — boron nitride coffin, 2 — 3D coil sets, 3 — fixation of Triple probe tips, 4 — fixation of rake probe Langmuir tips, 5 — printed circuit for reconnection of thin coil wires to thick coax cables, 6 — probe head manipulator

Moreover, triple probes at the top of the U-probe measure basic plasma parameters such as floating potential V_{float}, electron density n_e and temperature T_e. Measured temporal evolution of these parameters during the filament passage can be recalculated to its poloidal profile.

The U-probe consists of two identical towers, each housing a triple probe, radial array of 6 Langmuir tips (rake probe) and 3 sets of 3D coils each. The probe is inserted in the tokamak scrape-off layer near separatrix. Each tower consists of a boron nitride coffin and a covering lid with wall thickness of 5 mm. Space inside each tower is divided into two parts. One part houses radial array of the Langmuir probes made of graphite and the second part contains 3 sets of 3D coils, see Figure 1. The Langmuir probes array (rake probe) is oriented towards the poloidal plasma flow (i. e., to the midplane) and is located as near as possible to the toroidally oriented wall on side of incoming plasma current to minimize shadow effect of the second tower or another disturbance of the filament approaching because they have the key role for identification of the filaments. Coil systems are located at the "rear" side according to plasma current direction because of the electric current is more stable than electrostatic structures [5].

Probe manipulator

Probe is located at the outer wall of the COMPASS tokamak below the midplane (access port 14/15 AL). Diameter of the access port is 95 mm, see Figure 2. Probe manipulator does not only fix the probe in a given position but also it allows radial movement of the probe from separatrix to "fully-hidden" position in the access port on shot-to-shot basis. The manipulator allows change of inclination of the probe head and its rotation around axis to align the U-probe according to the magnetic field as well, i. e., axis of the towers perpendicularly to the separatrix and the U-probe plane perpendicularly to the magnetic field lines (about 10 degrees). This rotation and inclination had been set off-site in the mechanical workshop for the whole experimental campaign. Required precision of the alignment of the U-probe is less than 3 degrees [5]. Photograph of assembled U-probe before installation on COMPASS tokamak is given in Figure 3.

Signal path

Particular care was taken to detect properly also the high frequency components of the measured signals as the probe is focused on measuring fast turbulent structures. Therefore, each signal is amplified as close to the measuring element as reasonably achievable, i. e., at the air side of vacuum feed through. This implies that the length of the signal path for the raw signals is only about 40 cm.

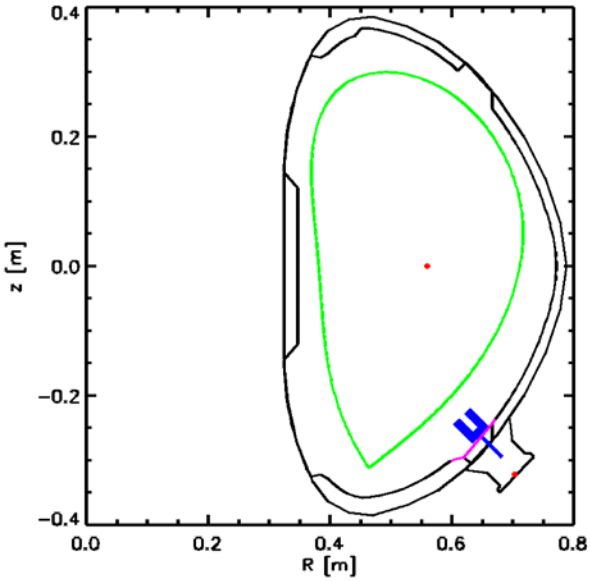

Figure 2. Schematic drawing of the U-probe inside the COMPASS tokamak. Black lines represent vacuum chamber, limiter and approximation of the used vacuum access port, green line represents standard position of last closed flux surface (LCFS) during flat-top phase of the discharge according the equilibrium recalculation by code EFIT++. U-probe is painted in blue.

Following the amplification, signals are led along approx. 15 m by coax cables to the data acquisition system DTACQ216 with proper impedance adjustment. Amplification electronics house the voltage dividers for floating potential measurement as well.

U-probe measurements

First results of measurements with the U-probe are presented in the following sections. These initial tests were performed in parasitic regime i. e., as a supplementary activity to the main experimental program of COMPASS campaign. Moreover, the U-probe was kept mostly far from separatrix to allow for conservative step-by-step regime of establishment of its compatibility with COMPASS plasmas. At last but not least, there were not enough free data acquisition channels with required performance and therefore, only data from some segments of U-probe were collected at each series of discharges.

Triple probe measurements

Triple probe is a tool for measurement of three points of Langmuir probe I-V characteristics. It measures floating potential (V_{float}), Voltage of one of the probes (biased with voltage of V_{bias} between each other) and current flowing through this probe. Figure 4 shows floating potential V_{float} measurement together with basic discharge parameters (Plasma current I_P and overall electron density n_e) and distance of the probe head from LCFS during the shot #5024. The Triple probe was not biased in this shot.

Rake probe measurements

Radial array of Langmuir tips (rake probe) is measuring radial profile of floating potential V_{float}. The characteristic change of the signal reveals existence and profile of the filaments. Therefore the rake probe is crucial for any filament analysis. Figure 5 shows signals of the first tip of the rake probe during the shot #5024 with enlarged section showing profile of passing group of the filaments.

Coil systems

Coil systems allow establishment of full vector of magnetic field $\boldsymbol{B}$ within 6 points of space (matrix 2×3). Figure 6 shows temporal evolution of all magnetic field components for first coil system of Tower A during the shot #4921.Dedicated components are not exactly components of the magnetic field according to standard tokamak coordinates due to inclination of the probehead according to local helical magnetic field line. Measured magnetic field changes show significant effect of the distance of LCFS and consequent plasma current density from the probe, toroidal component of magnetic field shows only the changes during the discharge, not the full magnetic field.

Summary

The U-probe designed for scrape-off layer observations of the electrostatic and magnetic properties of the plasma filaments in COMPASS has been installed and partially commissioned and put in operation.

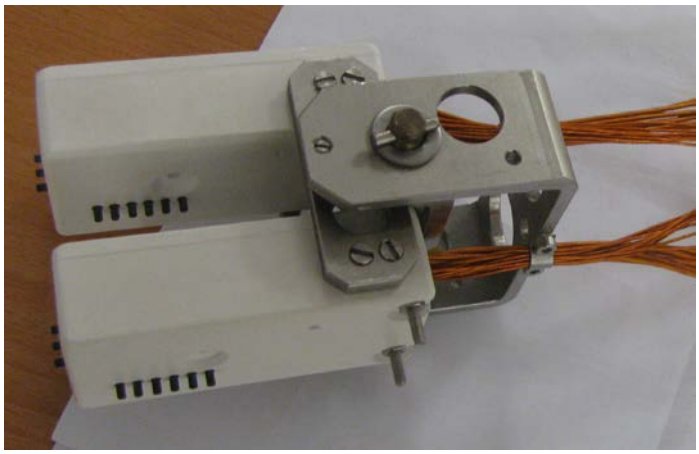

Figure 3. Photograph of assembled U-probe probehead.

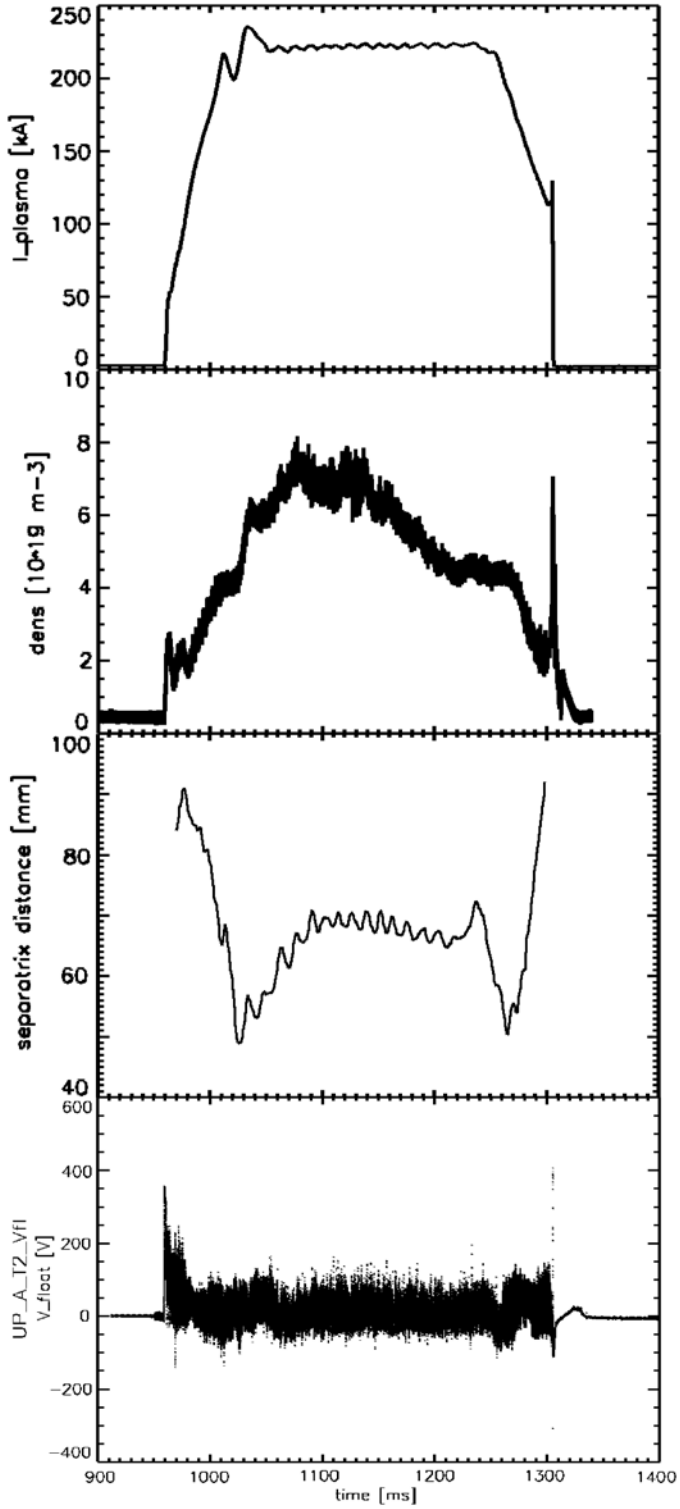

Figure 4. Measurements in shot #5024. From top: Plasma current I_P, line averaged electron density n_e, distance of the U-probe from the LCFS, Triple probe measured floating potential V_{float}.

Up to now, we were able to measure reasonable and similar profiles of floating potential on rake- and triple probes. Magnetic field components measured during the discharge reached reasonable values and expected temporal evolutions are observed. Future activity will concentrate on finishing the commissioning of n_e and T_e measurements by triple probes. Following that, more advanced analysis of measured data will aim at identification and characterization of plasma filament properties in the COMPASS SOL from both electrostatic and magnetic point of view.

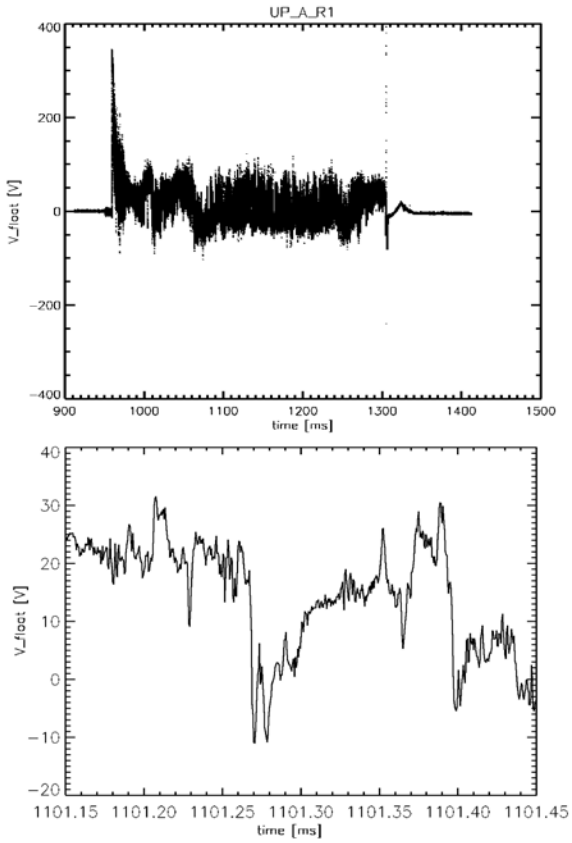

Figure 5. Floating potential V_{float} signal of rake probes R1 during discharge #5024 (top — whole discharge, bottom — short part of the discharge showing the group of filaments passing over the probe).

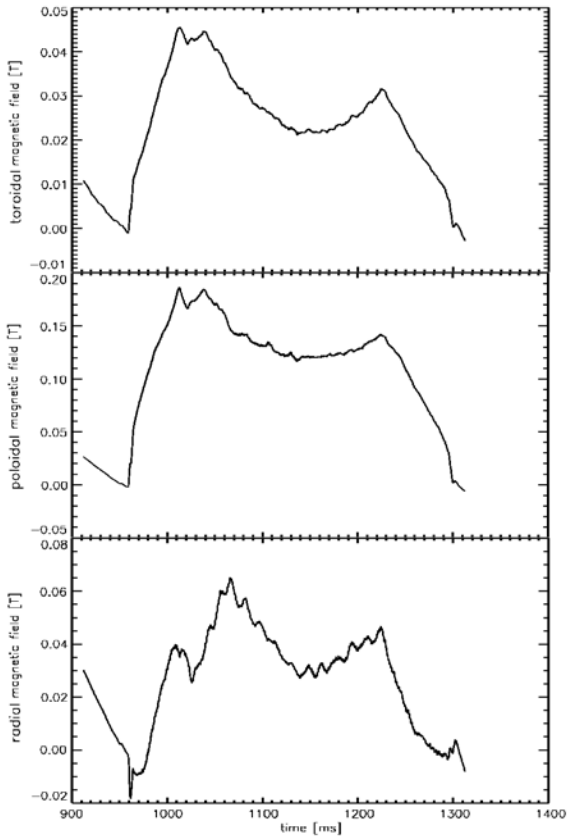

Figure 6. Evolution of magnetic field B components measured by the coil oriented mostly toroidally (top), poloidally (middle) and radially (bottom) during the shot #4921.

Acknowledgment. The work was supported by project of AS CR #AV0Z20430508, MSMT #7G09042 and #7G10072, #LM2011021 and Euratom. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] M. Spolaore et al., Direct measurements of current filament structures in magnetic-confinement fusion device, Physical Review Letters 102 (2009) 165001.

[2] M. Spolaore et al., Magnetic and electrostatic structures measured in the edge region of the RFX-mod experiment, Journal of Nuclear Materials 390–391 (2009) 448–451.

[3] E. Martines et al., Current filaments in turbulent magnetized plasmas, Plasma Phys. Control. Fusion 51 (2009) 124053.

[4] A. Schmid et al., Experimental observation of the radial propagation of ELM induced filaments on ASDEX Upgrade, Plasma Phys. Control. Fusion 50 (2008) 045007.

[5] K. Kovařík et al, U-probe for the COMPASS tokamak, in WDS'11 Proceedings of Contributed Papers: Part II — Physics of Plasmas and Ionized Media (eds. J. Safrankova and J. Pavlu), Prague, Matfyzpress (2011) pp. 227–232.