

Advanced probe diagnostics for measurement of electromagnetic properties of turbulent structures at the plasma edge of the TJ-II stellarator

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Abstract. Improved understanding of properties of the current filamentary structures in the edge plasma region is believed to allow better insight into development and possible control of the Edge localised modes (ELMs) and consequently, mitigation of their impact on the plasma performance and the first wall structures. We have focused on measurements of electric and magnetic properties of the filaments and electromagnetic features of the edge turbulence on TJ-II. We used a probe consisting of two 3D coil sets, two Hall sensors and 4 Langmuir tips. We present the first results of measurements with this probe on TJ-II stellarator.

1. Probe description

The new probe diagnostics combining a set of magnetic sensors and Langmuir tips in single probe head was recently commissioned on TJ-II. The sensing elements within the magnetic part of the probe are the three sets of magnetic sensors (3D inner coils set, 2D Hall probe, 3D outer coils set) and one platinum thermo-resistor PT-100 for temperature monitoring inside the probe head, see figure 1. The probes housing is made out of the non-magnetic stainless steel tube with outer diameter of 10 mm and the wall thickness about 0.5 mm. This housing provides electrostatic shielding of especially Hall sensors from the plasma and creates also a support structure for all the probe's components. The tube is slotted along its main axis so that it can be opened by removing the lid. The reasons for this configuration are to enhance penetration of the oscillating magnetic field inside the probe head through its stainless steel housing and to have a good access to all the components.

Each 3D coil set is labeled as inner or outer in the sense of its deepness of insertion in the vacuum chamber, i. e. the inner coils are in the front of the probe head with respect to plasma and outer are at the rear part of the probe head (side of wire output). The second part of labeling denotes orientation of the measuring element. Radial coils measure the magnetic field component along the main axis of the probe, parallel and perpendicular sensors have the sensing plane parallel and perpendicular to the plane of the slit respectively. Hall probe HP-P and HP-L are perpendicular and parallel respectively.

Signals of Hall probes are preprocessed by special electronics which provides adjustable amplification and stabilized source of supply current of 50 mA.



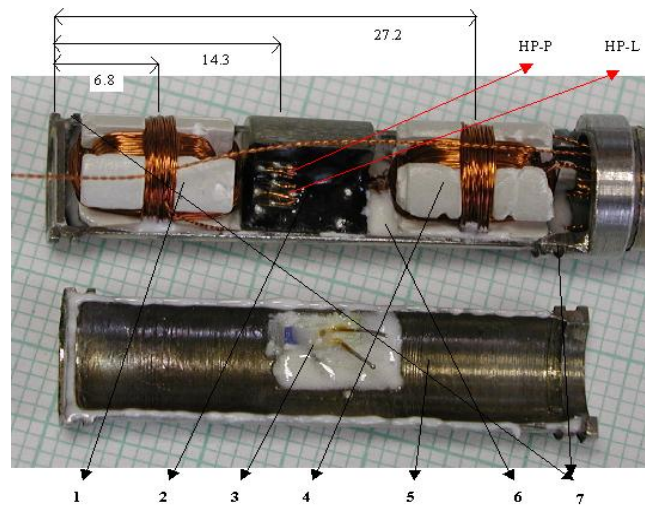


Figure 1. Detailed view of the magnetic part of the probe head (1: Inner 3D coil set, 2: 2D Hall probe, 3: PT-100 thermo-resistor, 4: Outer 3D coil set, 5: Removable non-magnetic stainless steel lid, 6: Special high vacuum compatible glue, 7: Rift used to accommodate several turns of wire for fixing the removable lid (5) to the rest of the probe's body).

Electrostatic part of the probe consisted of 4 Langmuir tips made from Tungsten. They are arranged at the corners of the square and pointing radially to the plasma core. Two of them are operated in ion saturation and two in floating potential regime.

2. Calibration of the probe

2.1. Coils

We performed calibration of all the coils within frequency range 1 – 300 kHz using the test bench which consists of RLC oscillation circuit, Rogowski coil for current measurement and long straight wire. Capacitor biased to 100V is discharged through resistor and inductance into the long straight wire creating a well defined calibration magnetic field. Output current with an amplitude of a few hundreds of Amps and waveform of damped sinusoid is generated. Frequency of output current is selected by proper values of capacity C and inductance L .

The effective area of all coils have significant flat top up to about 100 kHz. Basic parameters of the coils measured during the calibration are summarized in table 1.

Table 1: The basic properties of individual coils

Coil	R [Ω]	L [μ H] at 1 kHz	No of turns	Total area [cm^2]
$C_{\text{par}}^{\text{inner}}$	10.2	211.8	154	95
$C_{\text{par}}^{\text{outer}}$	7.4	111	110	63
$C_{\text{perp}}^{\text{inner}}$	7.8	88.9	102	46
$C_{\text{perp}}^{\text{outer}}$	7.2	112	113	61
$C_{\text{rad}}^{\text{inner}}$	4.8	39.6	75	38
$C_{\text{rad}}^{\text{outer}}$	4.2	32.6	60	37

2.2. Hall Probes

We performed absolute calibration of the Hall sensors in DC magnetic field provided by permanent magnets and measured by absolutely calibrated Lake Shore Hall probe. The permanent magnets provide calibration magnetic field up to 350 mT. The measured sensitivity of the Hall sensor HP-P is 383 mV/T and HP-L is 343 mV/T.

3. Installation on TJ-II

Probe was installed at stellarator TJ-II at the upper manipulator “Sonda D” on 21st May 2010. Slit of the magnetic part of the probe was oriented parallel to the toroidal magnetic field. So all the parallel sensors measure the poloidal component of the magnetic field and perpendicular sensors measure the toroidal component of the magnetic field. Signals of both 3D sets of coils were lead as three wires with shieldings connected together and used as common return signal. This type of connection was used for the whole signal track from the probe itself up to data acquisition system placed at the north wall of the stellarator hall. This wiring system provides significant reduction of the noise.

4. First results

4.1. Magnetic field profile measured by Hall sensors

We have measured toroidal and poloidal component of the magnetic field vector using the Hall sensors on shot-to-shot basis. Average values of the the magnetic field for each position are given in figure 2. The full red line is the theoretical model of the magnetic field on TJ-II.

The theoretical model is regrettably available only for inner part of the plasma. But, we have measured mostly in the plasma edge or out of the plasma. It is due to the fact that the Hall probes are about 17 mm from the leading edge of the probe-head and the probe cannot be moved too deep in plasma column without disturbing it. It is clear that the extrapolation of the theoretical model fits the measured values very well. Slight disproportion between theory and measurement for toroidal field is probably caused by improper orientation of the sensor. We assume the plane of the Hall sensor is exactly perpendicular to toroidal magnetic field, but it have inclination of up to a few degrees. This error denotes inclination of about 5 degrees which is at the edge of calibration precision.

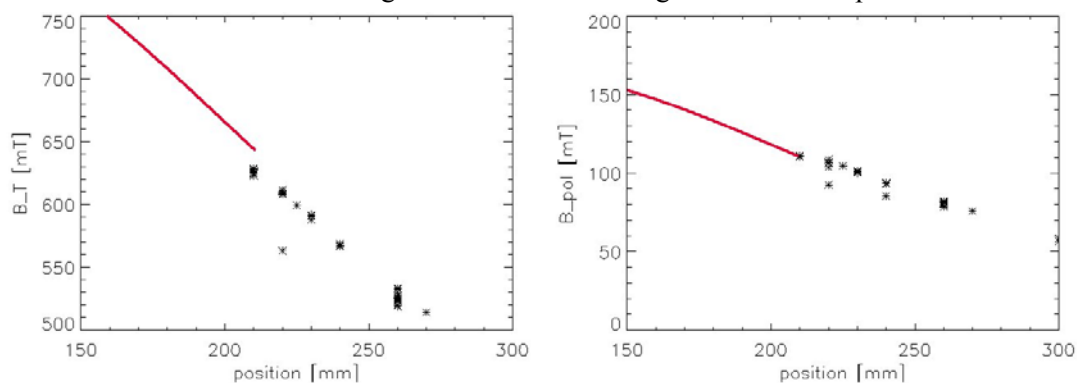


Figure 2. Comparison of measured profile of magnetic field (black stars) with theoretical model (red lines) in toroidal (left) and poloidal (right) direction.

4.2. Turbulence observation during discharge #25130

The phase sequence of the discharge #25130 is as follows. Magnetic field flat-top phase begins at 1000 ms and ends at 1300 ms. Plasma begins at 1020 ms with ECRH heating. At time 1090 ms, the ECRH is switched off and the phase of NBI starts. The NBI heating is finished at time 1160 ms and fast decay of the plasma follows.

Left pannels of Fig. 3 contain raw signals of inner radially oriented coil (upper) and Langmuir probes in ion saturation (middle) and floating potential (bottom) regime. Right pannels show the frequency spectra of the signals in phase of ECRH (green) and NBI (red). Noise spectrum is plotted in black. The Hall sensor frequency range is limited by 30 kHz by construction of the sensors themselves and therefore it is not used for studies of magnetic field fluctuations.

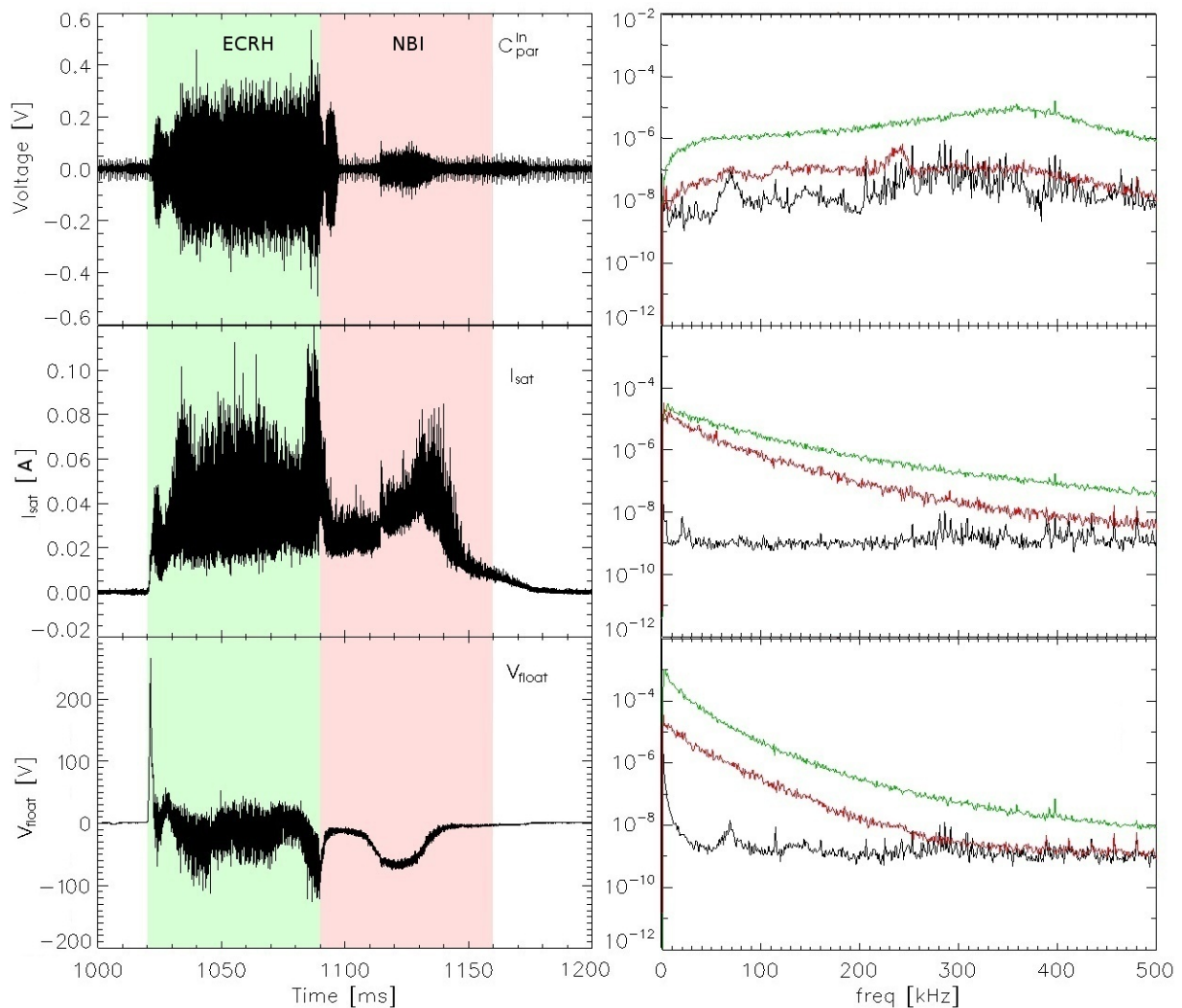


Figure 3. Raw signals (left) and frequency spectra (right) of the signals of inner radial coil (top), Ion saturation current (middle), and floating potential (bottom) during phase of ECRH (green) and NBI (red). Noise spectrum is plotted in black.

Level of both electrostatic and magnetic turbulence is significantly higher in ECRH phase compared to NBI phase of the discharge.

No particular features in frequency spectra indicating presence of significant instabilities or turbulent modes are observed neither in magnetic nor in electrostatic field.

5. Summary

Advanced probe diagnostics consisting of two 3D sets of coils, two Hall sensors and 4 Langmuir probes was engineered, manufactured, absolutely calibrated and successfully installed on TJ-II stellarator. Measurement of magnetic field profile agrees with the theoretical model. We have used this probe also to measure electromagnetic properties of turbulence in the edge plasma of TJ-II.

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