Tokamak GOLEM for fusion education - chapter 12

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The GOLEM tokamak [1, 2] is the oldest tokamak in the world. Currently, it serves mainly as an education device for students of tokamak physics. Remote control of the machine enables conducting experiments from all over the world. This contribution summarizes its main research topics of the last year.

Due to stray fields from current drive windings, the GOLEM plasma is shifted vertically toward the upper wall of the chamber and horizontally toward the low field side. Two external windings generating poloidal magnetic field were used to control the plasma position. A square waveform was selected as a predefined function and four KEPCOs connected in a parallel were used as power supply providing a current of 100 A. The resulting plasma position was determined from the signal of four Mirnov coils installed at the limiter. This predefined stabilisation successfully increased the discharge duration. Experiments are ongoing to determine the optimal current in the external windings and the number of turns per coil.

Two toroidally separated Langmuir probes (LPs) were used to study long-range correlations (LRC) in the edge plasma. LRC were sought at the expected GAM frequency $f_{GAM} \approx 15$ kHz in both V_{fl} and I_{sat} regimes in the range $r = 65-75$ mm. A low-frequency LRC candidate for GAM was, indeed, found and it was investigated whether it has GAM properties, that is, whether the two LP signals have high coherence and near zero cross-phase. However, the explored frequency region did not exhibit near-zero cross-phase and coherence above 0.7 at the same time at any radial position. This may suggest that GAM-like oscillations do not exist naturally in the explored plasma regime in the GOLEM tokamak. Future experiments will attempt to facilitate such a mode with edge plasma biasing.

Ion temperature was measured with 5 μs temporal resolution using a swept ball-pen probe. [3] The probe collector was swept from -30 V to +130 V at 100 kHz. The ion temperature T_{i} was obtained from the 4-parameter fit of the electron I-V characteristics branch

$$I(V) = I^{+}_{\mathrm{sat}}\left(\exp(\alpha_{\mathrm{BPP}})\cdot[1+K\cdot(V-\Phi)] - \exp\left(\frac{\Phi - V}{T_{\mathrm{i}}}\right)\right), \tag{1}$$

where $\alpha_{\mathrm{BPP}} = \ln\left(\frac{I^{-}_{\mathrm{sat}}}{I^{+}_{\mathrm{sat}}}\right) = 0.25 \pm 0.09$ for GOLEM [4], I^{-}_{sat} and I^{+}_{sat} are the electron and ion saturation current, respectively, Φ is the plasma potential and K is an empirical parameter facilitating linear increase of the electron current. The cut-off fitting technique (Fig. 1 left) was applied to minimise the role of the cut-off voltage V_{max} on the fit results. Fig. 1 middle shows the temporal evolution of T_{i} (measured with the described technique) and T_{e} (measured using the BPP+LP technique [5]) during a 1 ms time interval in main SOL. Fluctuations of the ion temperature ranging between 5 eV up to 40 eV reflect the turbulent behavior of the edge plasma and the resulting temperature histograms (Fig. 1 right) are positively skewed.

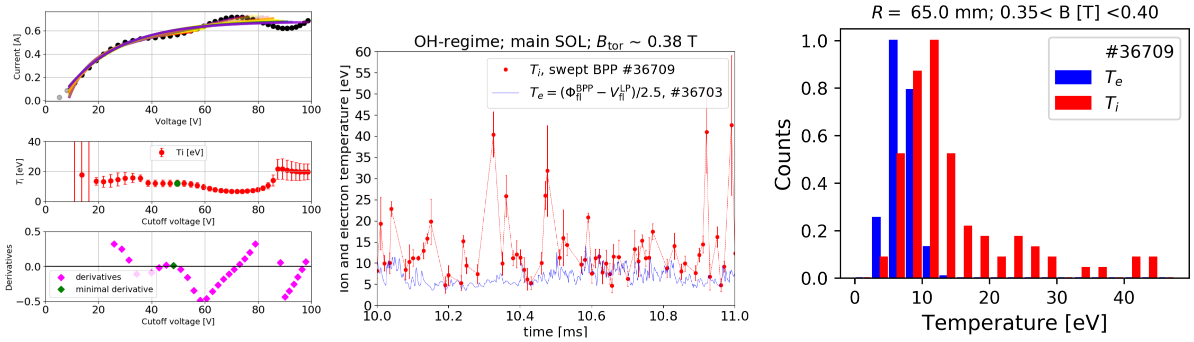

Figure 1: Left) Cut-off technique. Mid) Evolution of T_{i} and T_{e}. Right) Histograms of T_{i} and T_{e}.

Lithization tests were conducted in a small vacuum cube. A glow discharge ($U < 1$ kV, $I = 0.5$ A) in argon atmosphere between the chamber wall and a lithium electrode will be used in the future to create a homogeneous lithium film on the GOLEM wall. We have run tests of the lithization setup which revealed two critical problems. The first problem is the prompt oxidation of the metallic lithium during the installation of the electrode. The second problem is the risk of electrode melting. After about 15 minutes of the glow discharge, the electrode reached melting temperature. The solution is either to decrease the power in the circuit (preferably voltage) or to create a more homogeneous and unoxidized electrode to spread the power over a larger area. A positive result is that a spectral line of neutral Li has been observed in the glow discharge, meaning that lithium in, indeed, being sputtered from the electrode.

A new rail probe (RP) was constructed and used to measure the electron temperature. Rail probes are suitable for measurements in the tokamak divertor region as they can sustain high heat flux and reduce the sheath expansion effect. A probe head carrying a rail probe (length 40 mm, width 2 mm), a Langmuir probe (length 1.5 mm, diameter 1 mm) and a ball-pen probe [5] has been designed and installed on a new manipulator which can modify its inclination with respect to the toroidal magnetic field within $\pm 10^\circ$ with a precision of 0.6°. First comparative measurements of the electron temperature T_e using a swept RP, a swept LP ($f = 5$ kHz) and the BPP+LP technique [5] while varying the probe head inclination. The electron temperature was obtained from I-V characteristics using a four-parameter fitting formula with linear sheath expansion approximation, although the sheath expansion effect was observed smaller in the RP than in the LP. The temporal evolution of the electron temperatures of the RP, LP, and BPP is shown in Fig 2 for two different probe head inclination angles. In the flat-top phase with the constant plasma current, good agreement of the three probe techniques is observed even for a very small inclination angle.

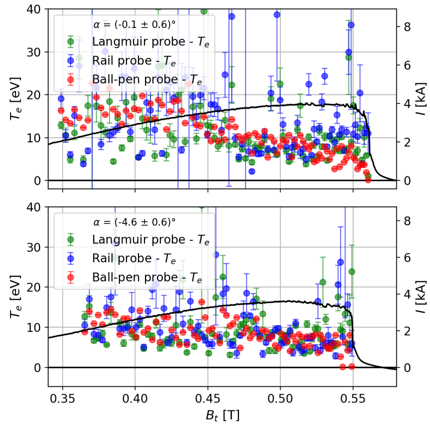

Figure 2: Comparison of T_e measured by LP, RP and BPP+LP.

Four scintillation detectors were installed to measure runaway electron energy spectra using HXR spectrometry. Two problems were encountered, shown in Fig. 3. Electronics of standard photomultiplier tubes of scintillation detectors does not withstand too large HXR fluxes from REs generated in tokamaks. This problem is noticeable in Fig. 3 left, when NaI(Tl) detector signal (green color) dramatically drops at around 8 ms, while other detectors measure intense HXR signal. The second problem is the pile-up effect, illustrated in Fig. 3 right. Compare for each detector the areas where the signal has piled up and the areas where individual peaks are detected. These two problems are partially related. Our goal is to find optimal setup in which they will be negligible. This can be done by ensuring sufficient lead shielding and distance from the GOLEM tokamak.

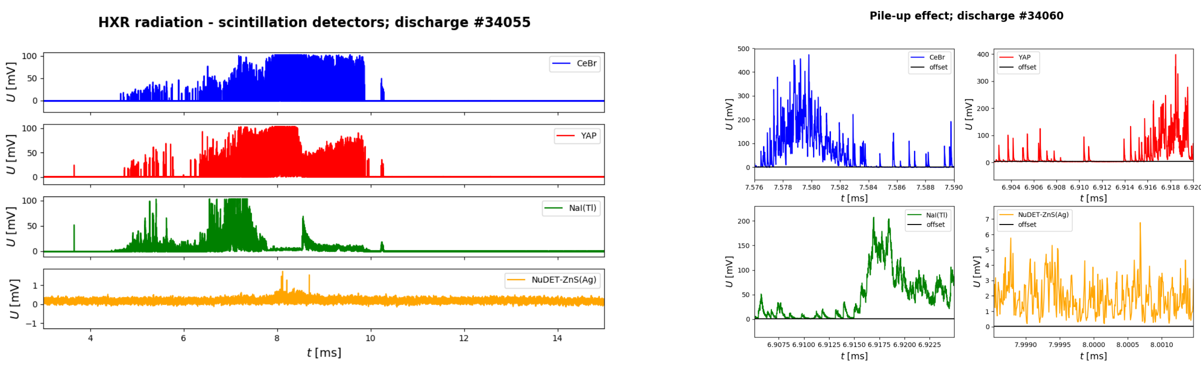

Figure 3: Left) Comparison of HXR signals from 4 different scintillation detectors. Right) Comparison of piled-up signals and individual peaks.

The ion saturated current I_{sat}, collected by a double rake probe, was used to demonstrate the presence of turbulent structures in the GOLEM edge plasma. Its radial profile was measured in the range $r = 37 - 90$ mm, with $r = 85$ mm being the limiter radius. The I_{sat} fluctuations histograms were found skewed to the right, which indicates the presence of high positive fluctuations - blobs - in the edge plasma. I_{sat} skewness remained positive throughout the measured region, only hinting at a fall to zero or negative values at its inner edge, see Figure 4. This suggests that the "blob birth zone" is located deeper in the chamber, in agreement with a basic LCFS reconstruction.

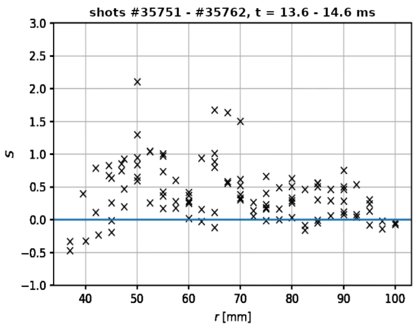

Figure 4: Radial profile of ion saturated current skweness.

A systematic comparison of two T_e measurement techniques, using a swept Langmuir probe and the BPP+LP technique [5], was carried out. The edge electron temperature is commonly measured by a swept LP. This method has been verified by time and numerous experiments and models, but applying it is rather complicated and time-consuming. Conversely, the innovative combined method using a floating LP and BPP probe is simple to apply and offers higher time resolution, but its experimental and theoretical verification is somewhat lacking. The two methods were compared in a series of identical discharges. The four-parameter V-A characteristics fit was found more appropriate, as the ion current branch did not fully saturate. The two methods yielded identical results, see Figure 5. We therefore suggest that the combined method is suitable for the essential task of measuring the edge electron temperature, as it can make tokamak edge T_e measurements readily available without the need for complicated and hand-checked data processing.

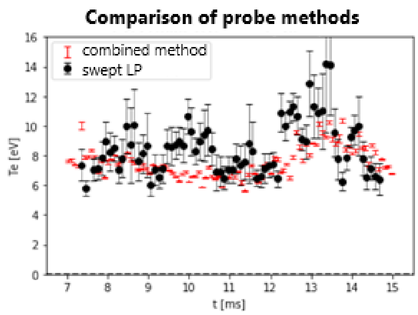

Figure 5: Time evolution of T_e.

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References

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