Tokamak GOLEM for fusion education - chapter 12

P. Macha[1,2], K. Hromasova[1,2], D. Kropackova[1], M. Lauerova[3], A. Socha[4], J. Malinak[1], D. Cipciar[5], J. Cecrdle[1], V. Svoboda[1], J. Stockel[2], J. Adamek[2], F. Papousek[1] , L. Lobko[1]

[1] *Faculty of Nuclear Sciences and Physical Engineering CTU in Prague, Czech Rep.* [2] *Institute of Plasma Physics AS CR, Prague, Czech Rep.* [3] *Gymnazium Nad Aleji 1952, Praha, Czech Rep.* [4] *Gymnazium a Strední odborna skola Cihelni 410, Frydek-Mistek, Czech Rep.* [5] *Faculty of Science, Masaryk University, Brno, Czech Rep.*

The GOLEM tokamak 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 main research topics of study of the last year. **Due to stray fields from current drive windings, the plasma on GOLEM is shifted to the upper wall of the chamber in the vertical direction and to the low field side in the horizontal direction during the discharge.** Therefore 2 external windings generating poloidal magnetic field are used to control plasma in both directions. A square waveform was selected as a predefined function and 4 KEPCOs connected in a paralell were used as power supply providing a current of 100A. Plasma position was determined from the signal of four Mirnov coils located at limiter. The influence of the horizontal magnetic field generated by the current in external coil can be observed as an effect on plasma column vertical displacement and the associated discharge duration. The optimal current in the external windings and the number of turns per coil for better discharge quality are still ongoing. **To facilitate future experiments with edge plasma potential biasing a system of two toroidally separated Langmuir probes (LP) was used to radially localize the long–range correlations (LRC) in the edge plasma.** Special focus was on the low-frequency oscillations at about the frequency of expected GAM which was estimated to be $\approx$ 15 kHz. The search of LRC was done in both V_{fl} and I_{sat} regimes with the radial position in a range from 65 mm to 75 mm from the center of the vessel. A low–frequency LRC candidate for GAM was found. To further claim that observed LRC are really GAMs, they have to have both high coherence and near zero cross-phase, when measured on the same poloidal but different toroidal positions. However, near–zero cross–phase and at the same time coherence above $\approx$ 0.7, was not observed in the expected frequency region in any of the shots. This could suggest either non–existence of GAM–like oscillations in the explored plasma regimes in GOLEM tokamak. **Ion temperature measurement with 5 μs temporal resolution was performed.** The technique [3] is based on the measurements of the electron branch of a ball-pen probe (BPP) I- V characteristic. The probe collector is biased with a voltage swept between -30V to +130 V at a frequency of 100 kHz. The ion temperature T_i is obtained from the exponential decay of the ion current as parameter of the 4-parameter fit:

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

Where $\alpha_{\mathrm{BPP}} = \ln\left(\frac{I_{\mathrm{sat}}^{-}}{I_{\mathrm{sat}}^{+}}\right) = 0.25 \pm 0.09$ was found for Golem. The values I_{sat}^{-} and I_{sat}^{+} represent the electron and ion saturation current, respectively. The parameter Φ denotes the plasma (space) potential. Note that the linear increase of the electron current with coefficient K is an empirical assumption. We have also applied a cut-off fitting technique (Fig 1 left) to all the I-V characteristics. This technique is based on varying the peak voltage, yielding one representative value of T_i from the flat-top phase of the I-V. An example of temporal evolution of T_i and T_e during 1 ms time interval in main SOL region is shown in Fig 1 mid. Fluctuations of the ion temperature ranging between 5 eV up to 40 eV reveal the turbulent behavior of the edge plasma. The resulting temperature histograms have a non-Gaussian shape with a peak at low temperatures and a tail towards high temperatures.

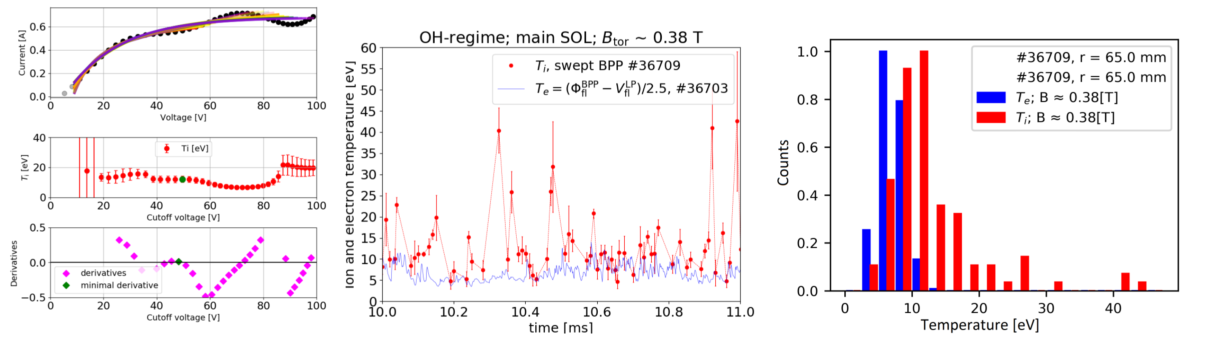

Figure 1: Left) Cut-off technique. Mid) Evolution of T_i and T_e. Right) Histograms of T_i and T_e.

With the goal of lithium wall coating utilization, several tests in a small vacuum cube have been conducted. A glow discharge (U<1 kV, I=0.5 A) in an argon atmosphere between the chamber wall and a lithium electrode will be used to create a homogeneous thin film on the wall. These test runs of the lithization setup re vealed a few critical problems that have to be dealt with before any further progress in the tokamak can be made. The most apparent problem is the prompt oxidation of the metallic lithium during the installation of the electrode. The other critical problem is a potential melting of the electrode. After about 15 minutes of the discharge, the electrode reached melting temperature. The only possible solution is to decrease the power in the circuit (preferably voltage) or 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, meaning the general idea to sputter the lithium with a glow discharge is correct. **The rail probe concept can sustain exceptionally high heat flux and reduce the sheath expansion effect.** Thus, it is suitable for the measurements in the divertor region of the tokamaks. A probe head consists of a rail probe (RP, length = 40 mm, wide = 2 mm), Langmuir probe pin (length 1.5 mm, diameter 1 mm), and ball-pen probe [4] has been designed and used on the tokamak GOLEM. The probe head shown in Fig 2 is installed on a newly designed manipulator, which can modify its inclination with respect to the toroidal magnetic field within +/- 10 degrees with a precision of 0.6 degree. First comparative measurements of the electron temperature T_e using a swept RP and LP (f = 5 kHz) and a floating BPP were performed for the different inclination of the probe head. We have observed a capability of the RP to reduce the influence of the sheath expansion effect. The electron temperature was obtained from I-V characteristics using a four-parameter fitting formula with linear sheath expansion approximation. The example of the temporal evolution of the electron temperatures of the RP, LP, and BPP is shown in Fig 2 for two different angles. In the flat-top phase with the constant plasma current, we see a very good agreement of all three probe techniques even for a very low angle of the probe inclination.

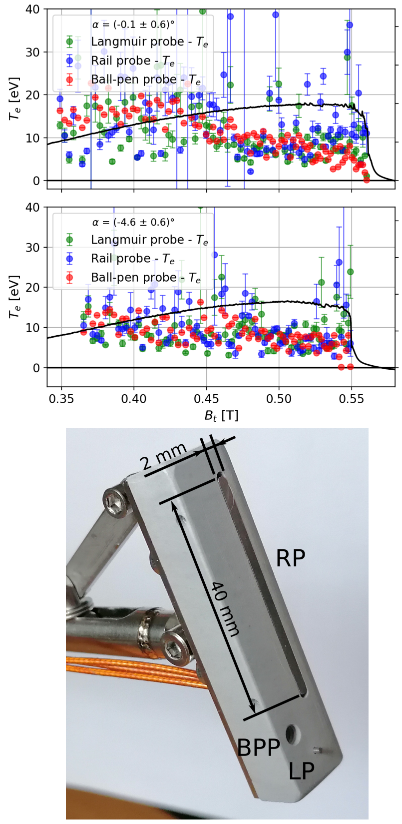

Figure 2: Top) Comparison of T_e measure by BPP, LP and RP. Bottom) Diagram of the combined probe head.

Measurement of the energy spectra of runaway electrons is generally very complicated. For this purpose, we try to use scintillation detectors for HXR spectrometry. Figures 3 show us the problems we have to face. 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 (green color) dramatically drops down around 8 ms, while other detectors measure intensive HXR signal. The second problem is illustrated in Fig 3 right, pile-up effect. For each detector, we can see piled-up areas and also areas of individual peaks for the comparison. These two problems are partially related and the main purpose of these measurements is to find optimal setup, in which these problems will be negligible. This is done by ensuring a sufficient lead shielding and distance from the GOLEM tokamak.

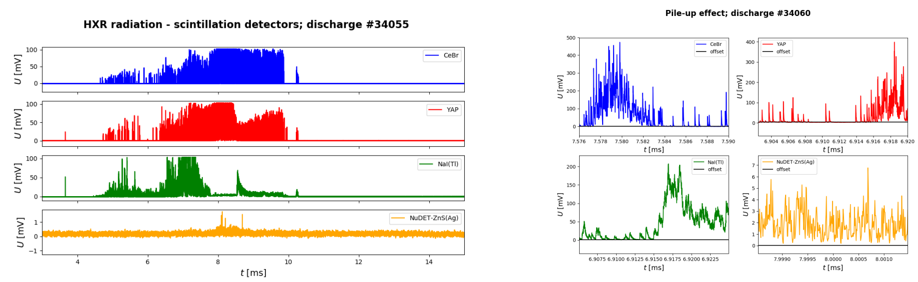

Figure 3: Left) Comparison of HXR signals from 4 different scintillation detectors. Right) Comparison of piled-up signals and individual peaks.

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, where r = 85 mm is the limiter radius. The pattern of I_{sat} fluctuations was investigated using histograms, which were found generally asymmetrical and skewed to the right. This 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. This, combined with a basic reconstruction of the LCFS position, suggests that the "blob birth zone", where pairs of blobs and holes are generated, is located deeper in the chamber. **The electron temperature T_e is an essential edge parameter,** and it 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 hitherto somewhat lacking. The two methods were compared in a series of identical discharges with the probes measuring the T_e profile. 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. We therefore suggest that the combined method is suitable for the essential task of measuring the edge electron temperature.

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