Tokamak GOLEM for fusion education - chapter 8

J. Cerovsky[1,2], M. Farnik[1,2], M. Sos[1,2], J. Svoboda[1], O. Ficker[1,2], M. Hetflejs[1], P. Svihra[1], M. Shkut[1], O. Grover[1,2], J. Veverka[1] V. Svoboda[1], J. Stockel[1,2], J. Adamek[2], M. Dimitrova[2]

[1] *Faculty of Nuclear Sciences and Physical Engineering CTU in Prague, Prague, Czech Rep.*

[2] *Institute of Plasma Physics of the CAS, Prague, Czech rep.*

Tokamak GOLEM is on of the oldest tokamaks in the world, currently located at the Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical university in Prague. It serves as an educational device and almost all experiments and development are done by students themselves. This contribution summarizes the main topics of the last year.

Plasma current stabilization. Tokamak GOLEM operation control currently does not enable achieving a flat-top plasma current regime. The aim of the proposed project is the implementation of a system providing the possibility to change the circuit resistance during the capacitor discharge sequence, in order to achieve and sustain the flat-top phase. A tabletop tokamak model, emerging as a byproduct, serves mainly as a proof of concept for putting the system into operation and secondly the as a training platform for diagnostics testing and tokamak operation. Fig. 1 shows current state of the tabletop model, with labelled key components, including power sources and the capacitor source which is discharged into the tokamak mock-up composed of an iron core coil and a loop imitating the tokamak vessel. The control unit is responsible for the flawless course of a discharge, diagnostics and data acquisition handling. Communication between components is provided by ethernet protocol through an integrated

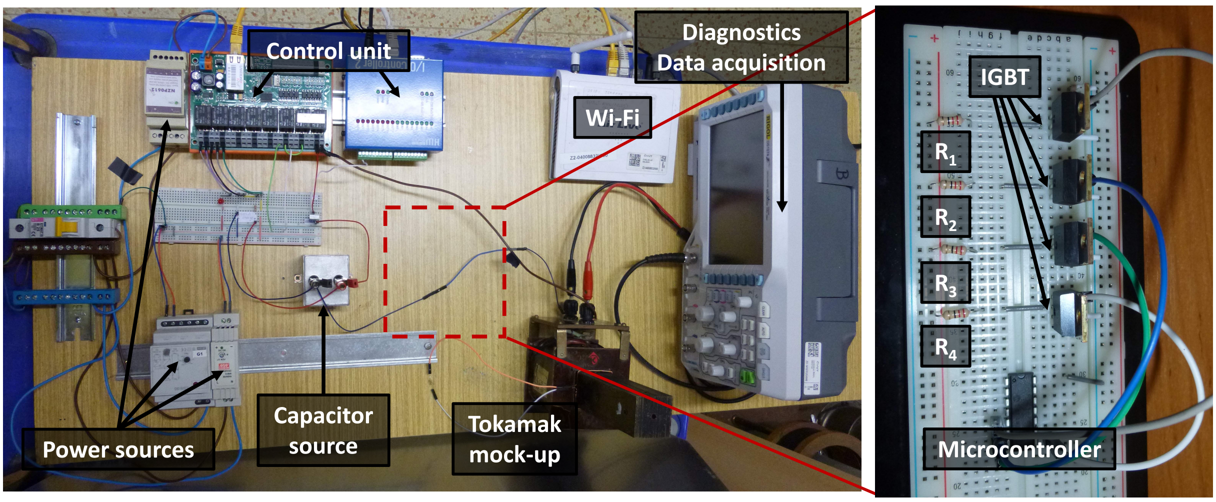

Figure 1: Tabletop tokamak model.

wireless router enabling remote control of the whole experiment. Next step consists of imple-

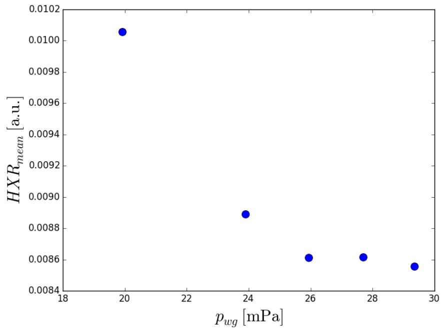

Figure 2: Dependence of HXR radiation on the initial working gas pressure.

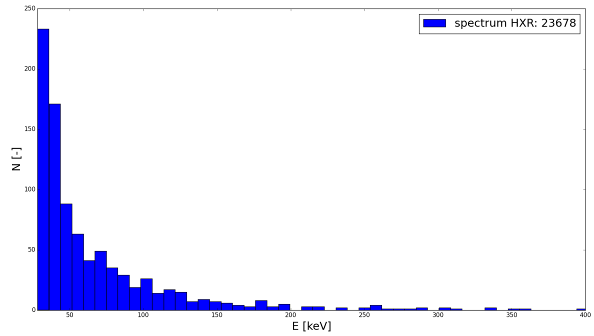

Figure 3: Energy spectrum of HXR radiation.

menting of a resistor array, indicated in Fig. 1, connected via IGBT transistors. Using a microchip controller a proper switching sequence will be designed to achieve the desired current evolution.

Runaway electron studies. Due to the low electron density ($4-6\cdot 10^{18}$ m^{-3}) and relatively high loop voltage ($4-6$ V), runaway electrons (RE) are present in almost every discharge on tokamak GOLEM. An scintillation detector is used for the observation of hard X-ray radiation (HXR), which is induced by the interaction of RE with the limiter. Fig. 2 shows the HXR spectrum from discharge # 23678. Our investigation focuses on the study of conditions for RE generation. Dependence of HXR radiation on initial gas pressure is shown in Fig. 3.

Development of semiconductor RE diagnostic. Due to their properties, semiconductor pixel detectors are suitable for detecting charged particles and X-rays. They are widely used at particle experiments, mostly for tracking or characterizing the type (possibly energy) of the radiation. One such detector is Timepix, developed by the CERN collaboration. It has 256×256 pixels with size of $55\times 55\mu$m. The idea of such application is to focus on a well defined region using a pinhole configuration and to observe an interaction of RE with the limiter. As the readout frequency of the detector is small, information was integrated over the whole discharge. Obtained results are promising in the terms of detection possibilities - clear difference between Timepix acquisitions during and after the discharge, and between RE and non-RE discharges.

Temperature estimation. Spectrometer HR+2000 Ocean Optics with resolution $\sim$ 0.035 to 6.8 nm (FWHM) was used to retrieve the spectrum of the plasma radiation in the range $200-110$ nm. Three most visible transitions of hydrogen were assigned as $2p\rightarrow 5d$ (434,047 nm), $2p\rightarrow 4d$ (486,136 nm) and $2p\rightarrow 3d$ (656,238 nm) and the pyrometric line method was used to estimate the temperature. The obtained temperature was compared with the temperature measured by other methods, showing comparable temporal evolution. However, temperature obtained by the spectroscopy method was by two orders of the magnitude lower than the temperature calculated by the Spitzer formula.

Jupyter data analysis platform. An interactive data analysis and visualization platform based on the JupyterHub web application has been deployed as a service on the GOLEM web server. This web application enables students participating in remote training courses and other activities to immediately start processing and analyzing data without the need for them to install and set up a similar platform themselves, all they need is a web browser. The platform is integrated with the database of experimental results and offers modern scientific data processing and plotting algorithms on par with MATLAB through the use of the free Anaconda Python distribution, in particular the NumPy, SciPy and Matplotlib libraries.

Breakdown probability studies. Investigation of the vacuum characteristics, influenced by the chamber leak, and of subsequently affected breakdown probability was performed and an attempt on the Paschen curve determination was made. The main aim of the study was to compare the results from the periods before the leak, during the leak and after the leak. The shots were assessed from two aspects - investigating breakdown probability and breakdown voltage. Slight increase of the breakdown voltage after the formation of the leak can be seen from this data and no decrease after the leak mitigation.

Measurements with the Ball Pen Probe. The combined probe head composed of the Ball Pen Probe (BPP) and a single Langmuir probe (LP), see Fig. 4 was used on the GOLEM tokamak [1] for direct measurements of the plasma potential and the electron temperature with a high temporal resolution. BPP measures directly the plasma potential ϕ and LP monitors

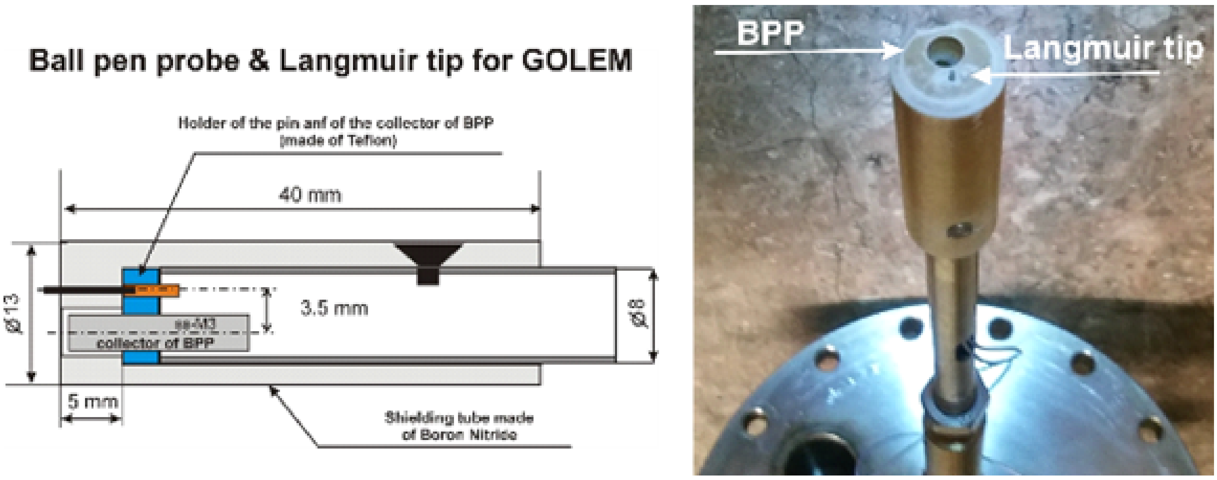

Figure 4: Combine probe head. Left - design, right - picture.

the floating V_{fl} at the same magnetic surface. It was shown [2] that the electron temperature is derived according a simple expression $T_e = \frac{\phi - V_{fl}}{\alpha}$ (1). The coefficient proportionality α is a function of ion mass, and for hydrogen plasma on the CASTOR tokamak, $\alpha = 2.8$. Aim of current experiment is to check, if α is a function of the toroidal magnetic field B_{TOR}. We measure the IV characteristics of LP (probe = 65 mm from the centre of the tokamak vessel) in four reproducible discharges. The electron temperature and the floating potential are determined either by a standard four parameter fit, or by First Derivative Technique [3], which measure the Electron Energy Distribution Function (EEDF). Results are shown in Fig. 5. We found that

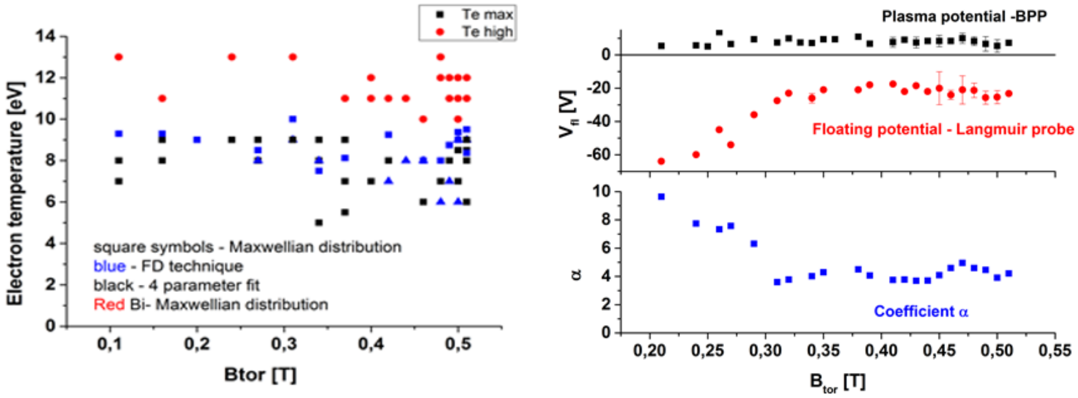

Figure 5: Left - Electron temperature versus the toroidal magnetic field in discharges # 23 447, 23 449, 23 450, 23 451. Right - Plasma and floating potential and the resulting coefficient α versus B_{TOR}.

the EEDF is bi-maxwellian in some cases, with a tail characterized by higher electron temperature (red symbol in left panel of Fig. 5). However, majority of data shows maxwellian EEDF (blue symbols), which agree quite well with results of the four parameter fit (black symbols). The average electron temperature is independent on B_{TOR}, being around 8 eV. The resulting coefficient α is plotted versus B_{TOR} in the right panel of Fig. 5 according expression (1) together with the plasma and floating potentials. It is seen that α is independent on B_{TOR} in the range of 0.3-0.5 T, being around 3.8. However, α significantly higher for $B_{TOR} < 0.3$T. The reason is not yet understand and additional experiments are in order to find an explanation.

Acknowledgement: This work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS17/138/OHK4/2T/14 and supported by the Czech Science Foundation project GA 15-10723S CSF.

References

[1] V. Svoboda, et al., Fus. Eng. and Des. **68**, 1310-1314 (2011)

[2] J. Adamek, et al., Contrib. Plasma Phys. **54**,No. 3, 279-284 (2014)

[3] Tsv. K. Popov, et al., Plasma Sources Sci. Technol.**25**, 033001 (18pp) (2016)