

**PROGRAMME OF COORDINATED RESEARCH ACTIVITIES**

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**Annual Progress Report for Contracts**

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CRP code: F13019	CRP title: Network of Small and Medium Size Magnetic Confinement Fusion Devices for Fusion Research
Contract Number: 22782	Contract title: Scientific and education activities on the GOLEM tokamak in the framework of the IAEA CRP
Institute Name: Czech Technical University	
CSI: Vojtěch SVOBODA	Alternate CSI:
Progress Report for year: 3 (year 1, 2, 3...)	Period covered: (2020-09-01 - 2021-08-31)

1. Detailed programme of work, as planned at the beginning of the period, taking into account the recommendations given during Research Coordination Meetings (RCMs) and/or through communication with the Project Officer:

**2.2.14.1. Main research activities proposed**

The scientific activities focus on the field of plasma edge studies using advanced probe techniques and developing diagnostics for runaway studies.

**2.2.14.3. Education activities**

In the CRP context there are two planned education activities: GOMTRAIC, a week of hands-on experiments at the GOLEM tokamak, and a set of remote participation training courses.

2. Results achieved in comparison with the planned programme of work.

\* plasma edge studies using advanced probe techniques

**Hydrogen and Helium Plasmas in the GOLEM Tokamak**

The helium plasma properties and confinement remain an important area of research in modern fusion devices. This work is dedicated to the helium plasma initiation and control in a small-scale tokamak GOLEM compared to hydrogen plasma. Helium and hydrogen plasmas are comprehensively compared and the optimum operational conditions for the start-up are found. Long-range correlations between low-frequency (< 50 kHz) electrostatic and magnetic oscillations are found, as well as broadband (< 250 kHz) magnetic oscillations resolved in frequency and wave vector in helium plasma. More info in the article [Saranch+21]

**Electron temperature measurements using rail probe on the tokamak GOLEM**

Problem of measurement of edge plasma parameters with a new type of probe, the so-called rail probe is investigated. The advantage of this probe is that thanks to its design it can withstand extremely high

heat fluxes and at the same time behaves as a proud Langmuir probe for a certain non-zero angle of incident field lines. The thesis summarises the fundamental physics of the Langmuir probe and sheath expansion. A manipulator was developed and constructed to allow tilting of the probe head, which includes a proud Langmuir probe and a ball-pen probe in addition to the rail probe. Comparative measurements of the electron temperature using all of these probes are presented and show conformity. The dependence of the obtained plasma parameters on the head tilt angle is also investigated. The measured data are compared with a 2D PIC simulation performed for a GOLEM tokamak. These 2D PIC simulations will be an essential part of the rail probe's development for the COMPASS Upgrade tokamak. More info in the bachelor thesis [Jirch] (in czech). The publication in the journal is currently being prepared.

### **Ion and electron temperature study in the edge plasma of the tokamak device**

Systematic ion and electron temperature measurements in the scrape-off layer (SOL) of two tokamak devices (COMPASS and GOLEM) are considered. Results are obtained using a fast swept ball-pen probe with unprecedented temporal resolution (10  $\mu$ s). Moreover, an improved analysis technique is presented which increases the amount of relevant data obtained in comparison to previously published research. The results with high temporal resolution indicate non-Gaussian ion temperature histograms with a peak at low temperatures and a high temperature tail associated with blobs. The blobs are originating in the vicinity of last closed flux surface and propagate perpendicularly to the magnetic field lines through the SOL plasma. The resulting fast measurements are used to simulate the I-V characteristic of a slow swept (3 ms) retarding field analyzer (RFA). The exponential part of the RFA-like I-V characteristic also determines the ion temperature, but with low temporal resolution (3 ms). The ratios of the ion to electron temperatures are studied for different plasma densities. We observed that the ratio depends on the line-average plasma density and it is close to 1-2 in the vicinity of LCFS and 3-4 in the main SOL. A study of the ion temperature fluctuations shows an agreement with a stochastic model for intermittent turbulence in SOL. More info in the bachelor thesis [Darst]. The publication in the journal is currently being prepared.

\* developing diagnostics for runaway studies.

### **The Runaway Electrons Production Dynamics Dependence on the Breakdown Phase of the Tokamak Plasma**

The effect of the breakdown phase on subsequent plasma parameters was investigated remotely in GOLEM tokamak. The dependence of breakdown voltage and the breakdown time versus the time delay between the trigger of the toroidal magnetic field  $B_t$  and the trigger of toroidal electric field  $E_t$  for different groups of the pressure magnitudes is built. The performed experiments have shown that for GOLEM tokamak the shorter is temporal delay - the better mean plasma parameters are obtained. In addition, the breakdown phase was discussed more detailed. In the discussion the analysis of the avalanche phase of the breakdown was made. The dominant mechanism of particle losses during avalanche phase, future steps, tasks were discussed and set. More info in the article [Sius+21].

**Runaway electron study at the COMPASS tokamak using the Timepix3-based silicon pixel detector with SPIDR 10 GBps readout.** More info in the article [Kul21].

\* educational activities

**Foressen GOleM TRAIning Course (GOMTRAIC 2021)**

GOleM TRAIning Course (GOMTRAIC2021) was not organized due to persistent problematic pandemic situation.

**Education and training of students**

Experiments related to CRP project triggered bachelor and master thesis at the CTU:

Bachelor projects:

- Jiri Malinak: Electron temperature measurements using rail probe on the tokamak GOLEM. Defended 2020.

Master thesis:

- Dario Cipciar: Ion and electron temperature study in the edge plasma of the tokamak device. Defended 2020.
- Filip Papousek: Impact of swept edge plasma potential biasing on turbulence in tokamaks

Overall info about student's projects at the tokamak GOLEM in the article **Tokamak GOLEM for fusion education - chapter 12** [Mac21].

Hands-on/ on site tokamak GOLEM projects

- For Students (bachelor level) of the FNSPE CTU in the frame of the Basic experimental laboratory. This year, again remotely due to the pandemic situation. March 2021.
- Two projects for extremely skilled high school students: Martina Lauerova (Electron temperature measurement at tokamak GOLEM using electric probes) and Ales Socha („Blob birth zone“ position in the edge plasma of tokamak GOLEM)

Training of students has also been performed remotely, exploiting a unique feature of the GOLEM tokamak, which can be operated via Internet. Several on-site as well as remote courses were organized in the period 2020 – 2021, among these, major events were:

- Remote practice for Budapest University of Economics and technology, Hungary, November 2020.
- Remote workshop for the 9th International Workshop and Summer School on Plasma Physics (IWSSPP), Kiten, Bulgaria, November 2020.
- Remote practice for Torino University, Italy, December 2020.
- Remote practice for Eindhoven University, Netherlands, January 2021.
- Remote workshop for Fusion Master gathering on Cadarache, France, February 2021.
- Remote practice for Moscow University, Russia December 2020, March and April 2021.

Miscellaneous:

- Demonstration in the frame of the Fusion Teacher day. October 2020.

3. Papers published and dissemination at national and international conferences on work performed under this Project (please enter a web-link or attach copies to this progress report):

[Sius+21]

Siusko, Y., Svoboda, V., Stockel, J., Garkusha, I., Solyakov, D., Girka, I., . . . Shchibrya, A. .

Breakdown phase in the golem tokamak and its impact on plasma performance. *Ukrainian Journal of Physics*, 66(3), 231-239 (2021). doi:10.15407/ujpe66.3.231

[Kul21] Kulkov, S., Marcisovsky, M., Svihra, P., Ficker, O., Cerovsky, J., Macusova, E., Weinzettl, V., Beuzekom, M., Fransen, M., Bren, D., Linhart, V., Svoboda, V., Tunkl, M. "Runaway electron study at the COMPASS tokamak using the Timepix3-based silicon pixel detector with SPIDR 10 GBps readout". In: vol. 2021-July. Europhysics conference abstracts. 2021, P3.1006. isbn: 979-10-96389-13-1. url: <http://ocs.ciemat.es/EPS2021PAP/pdf/P3.1006.pdf>.

[Mac21] Macha, P., Hromasova, K., Kropackova, D., Lauerova, M., Socha, A., Malinak, J., Cipciar, D., Ceardle, J., Svoboda, V., Stockel, J., Adamek, J., Papousek, F., Lobko, L. "Tokamak GOLEM for fusion education - chapter 12". In: vol. 2021-July. Europhysics conference abstracts. 2021, P4.1028. isbn: 979-10-96389-13-1. url: <http://ocs.ciemat.es/EPS2021PAP/pdf/P4.1028.pdf>.

[Jirch] Jiri Malinak. "Electron temperature measurements using rail probe on the tokamak GOLEM." Bachelor project at the CTU Prague, 2021. url: <http://golem.fjfi.cvut.cz/wiki/Presentations/Students/BachelorProjects/21MalinakJiri.pdf>

[Darst] Dario Cipciar. "Ion and electron temperature study in the edge plasma of the tokamak device". Master thesis at the CTU Prague, 2021. url: <http://golem.fjfi.cvut.cz/wiki/Presentations/Students/MasterThesis/21DarioCipciar.pdf>

[Saranch+21]  
George Sarancha, Alexey Drozd, Stanislav Ganin, Daniela Kropackova, Ivan Kudashev, Vladimir Kulagin, Martina Lauerova, Alexander Melnikov, Nikita Sergeev, Oleg Krokhalev, Jan Stockel and Vojtech Svoboda. Hydrogen and Helium Plasmas in the GOLEM Tokamak. Prepared for publication in *Questions of Atomic Science and Technique*.

4. Activities included in the programme of work which were planned, but were not implemented. Please state reason (i.e.: delays, issues encountered):  
- Persistent problematic pandemic situation.

5. Detailed programme of work for the coming year, taking into account the recommendations given during RCMs and/or through communication with the Project Officer (to be used as reference for the next Progress Report):

**Main research activities proposed:**

The scientific activities continues to focus on the field of plasma edge studies using advanced probe techniques and developing diagnostics for runaway studies.

**Education activities proposed:**

In the CRP context there are again two planned education activities based on first year experience: GOMTRAIC #2, a week of hands-on experiments at the GOLEM tokamak, and a set of remote participation training courses.

CSI Name and signature:

Date: 18.10.2021

Vojtěch Svoboda

