

Progress report on the project IAEA Research Contract No: 22782

in the frame of

IAEA Coordinated Research Project F13019, 'Network of Small and Medium Size Magnetic Confinement Fusion Devices for Fusion Research'

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The following tasks have been executed in the year May 2018- April 2019

Operational domain in hydrogen plasmas on the GOLEM tokamak

A series of discharges in Hydrogen were performed in two experimental sessions in different tokamak vessel configurations. The vessel was not conditioned before the first session, while inductive heating of the vessel and cleaning glow discharge were applied before the second session. Experimental results from both sessions are compared, and optimum operational conditions for the majority of key plasma parameters are determined. It is found that plasma performance with a properly conditioned vessel is significantly better, as expected. In particular, a noticeable increase of discharge duration, and of the electron temperature is observed

More info at: Vojtech Svoboda, Maya Zhekova, Miglena Dimitrova, Plamena Marinova, Ales Podolník, and Jan Stockel. Operational domain in hydrogen plasmas on the golem tokamak. *Journal of Fusion Energy*, Mar 2019. ISSN 1572-9591.
doi:<https://doi.org/10.1007/s10894-019-00215-7>.

Online experimentation at the GOLEM tokamak

The GOLEM tokamak offers students and other interested parties the opportunity to gain “hands-on” experience through online experimentation in the field of plasma physics and controlled thermonuclear fusion in tokamaks. A typical online experiment scenario is outlined. The new web application facilitating safe, easy and efficient online experimentation, including a live, real-time view of the experiment is described in detail. Simple access to the open and extensive database of experimental results is demonstrated. Finally, the wide range of possible experimental topics from past -and applicable to future- online experimentation sessions is reported.

To be presented at 5th Experiment@International Conference 2019 ,
<http://expat.org.pt/expat19/about/>

More info at: Ondrej Grover , Vojtech Svoboda, and Jan Stockel. Online experimentation at the GOLEM tokamak. Submitted for publication in the IEEE Xplore digital library.

Study of Runaway Electrons in GOLEM Tokamak

High loop voltages and low-density discharges at GOLEM tokamak present favorable conditions for the study of runaway electrons. In this paper, we discuss the interplay between magnetic hydrodynamic (MHD) fluctuations and runaway electrons. In quasi-periodic events, it was observed that tearing modes strongly destabilize during large HXR signals due to the runaways. Tearing modes become stable, when HXRs are suppressed. Causality of events is still not clear, since during the HXRs generation, toroidal electric field also increases, as indicated by loop voltage signal. A detailed analysis will be presented during the conference to understand the problem.

To be presented at the 3rd European Conference on Plasma Diagnostics, Lisbon.
<https://www.ipfn.tecnico.ulisboa.pt/ECPD2019/welcome.html>

Design and Development of Probe for the Measurements of Runaway Electrons Inside the GOLEM Tokamak Plasma Edge

Repeatable discharges with high loop voltage and low-density in GOLEM tokamak [1] present good experimental conditions for the study of runaway electrons (RE). A probe is being designed and developed for the spectral measurement [2] of RE energy inside and near the GOLEM tokamak plasma edge. Probe design is based on simulation results of FLUKA code [3] that estimates the energy absorbed by the filters of high-density materials and scintillating crystals. Simulations performed for the electron beams of energy 1-10MeV suggest that runaways may have energy much higher than 1MeV in the GOLEM tokamak. In the simulations, graphite, stainless steel, molybdenum and tungsten were tested to filter the supra-thermal electrons. Since having low-Z and being sensitive to γ -radiations and electrons, YSO [2] scintillation crystal is chosen for the probe. However, flexible design of the probe allows different scintillating crystal and filter materials inside it. In the conference, design, development and preliminary results of the RE measurements by the probe will be presented.

To be presented at the 46th European Physical Society Conference on Plasma Physics, Milan. <https://www.epsplasma2019.eu/>

GOleM TRAIning Course (GOMTRAIC 2019)

GOleM TRAIning Course (GOMTRAIC2019) was held at the faculty of Nuclear Sciences and Physical Engineering in the Czech Technical University in Prague, Czech Republic during March 04-08, 2019. The training course was organized in cooperation with Fusion Education Network (FUSENET) and International Atomic Energy Agency (IAEA).

Sixteen students (from undergraduate to doctoral level and ten countries) participated in the course to have hands-on experience of tokamak operation and perform experiments on the GOLEM tokamak. Following students attended the course-

The workshop offered an interactive course on fundamental and advanced toroidal plasma physics. The course covered important aspects of experimental work on tokamaks. The course was supervised by Vojtěch Svoboda, Jan Stckel, Pravesh Dhyani, Mykyta Vavarin, Ondřej Grover, Kateřina Jiráková, Jaroslav Čerovský and Petr Macha.

For the preparation of data processing, one week before the workshop, participants and task supervisors communicated to discuss the experiment plans, data analysis, related softwares and the routines used during the workshop.

On first day (March 3) of the GOMTRAIC, all the students were introduced with GOLEM tokamak, where they measured fundamental plasma parameters like loop voltage, plasma current, toroidal magnetic field and electron temperature under the supervision of Vojtěch Svoboda. Subsequently, access to the GOLEM data acquisition system and basic data analysis methods were explained by Ondřej Grover.

On the second day (March 4), a talk on tokamak physics and basic diagnostics was given by RnDr. Jan Stckel that was followed by tasks-based lectures by other task supervisors. Afterwards, students discussed their experiment plans with their respective supervisors and performed experiments on the advanced topics as planned.

Third and Fourth day (March 5-6) were fully dedicated to the task-based experiments and data analysis. Students planned and performed their experiments on their own, developed simple computational (Python/ MATLAB) scripts to analyze the data with the help of task supervisors. A visit to COMPASS tokamak was held in the afternoon of March 5 to motivate them for the fusion research further.

On the last day (March 7) of the course, each group of students presented and discussed their experiment results and future plans.

Education and training of students

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

Bachelor projects:

- Filip Papousek: Impact of swept edge plasma potential biasing on turbulence in tokamaks
- Vojtech Fiser: Real-time control of technological processes at the GOLEM tokamak

Foreseen Master thesis

- Petr Mácha: Fast measurements of electron temperature on the GOLEM tokamak by means of Tunnel Probe

Hands-on/ on site tokamak GOLEM projects

- For Students (bachelor level) of the FNSPE CTU in the frame of the Basic experimental laboratory.
- SCIWEEK – Science week for high school students from Czech Republic
- September 2018: Night of Scientists for broad public.
- Two projects for extremely skilled high school students: Nela Sedlackova (RE studies) and Daniela Kropackova (Plasma edge studies)

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 2018 – 2019, among these, major events were:

- Remote workshop for the Eight International Workshop & Summer School on Plasma Physics at Black Sea from Sunday, Kiten, Bulgaria, 10th to Saturday, 17th June 2018. <https://iwsspp.plasmer.org/>
- Remote practice for Budapest University of Economics and technology, Hungary 19th, November 2018
- Remote practice for Padova University, Italy 23rd, November 2018
- Remote practice for Eindhoven University, Netherlands 18th, December 2018
- Remote practice for Torino University, Italy 20th, December 2018
- Remote workshop for the 5th ASEAN School on Plasma and Nuclear Fusion, 21-25 Jan 2019, Mahidol University, Thailand, <https://sites.google.com/site/fusionschoolth/asprf2019>
- Remote practice for Fusion Master gathering in Cadarache, France 19th, February 2019
- Remote practice for Charkov University, Ukraine 13th, March 2019
- Remote demo from ASDEX tokamak, Germany 25th, March 2019
- Remote practice for Moscow University, Russia 9th, April 2019

Tokamak GOLEM for fusion education – chapter 10

Students of the Czech Technical University in Prague participate on the development of the tokamak operation and its diagnostics base and are involved in the simple projects contributing to the main stream of the tokamak plasma physics and technology.

- Calibration of the ball-pen probe [2] and measurements of plasma parameters in H and He plasma, based on a shot-to-shot method using movable combined probe head composed of the ball-pen and Langmuir probes.
- Mass spectrometer PrismaPlus. Integrating of the spectrometer into the system will make the automatic data collection possible, with applications, e.g., calibration of the pressure gauge and improvement of wall conditioning methods.
- The parallel Mach number is measured by using the double tunnel probe.
- Double rake probe for studying plasma turbulence. Edge plasma potential biasing is a way to induce shear flows that suppress the turbulence.
- Research on runaway electrons (RE) is focused on two topics: i) segmented semiconductor detector placed in vacuum chamber for various measurements and ii) probe based on scintillating materials alternating with heavy absorbers able to measure RE energy

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