The GOLEM tokamak bibliography

The tokamak GOLEM team

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Official GOLEM Articles

Abbasi et al.: Plasma diagnostics using fast cameras at the GOLEM tokamak **AbbasiFUSENGDES23**

S. Abbasi et al. "Plasma diagnostics using fast cameras at the GOLEM tokamak". In: *Fusion Engineering and Design* 193 (2023), p. 113647. ISSN: 0920-3796. DOI: https://doi.org/10.1016/j.fusengdes.2023.113647. URL: https://www.sciencedirect.com/science/article/pii/S0920379623002302.

Abstract: Tomographic inversion of radiation determines spatial distribution of tokamak plasma radiation sources using line integrated plasma projections data. For measurements of the projections, fast visible radiation matrix cameras became broadly applied on tokamaks in recent past. These novel cameras opened new possibilities in high temperature plasma studies. The GOLEM tokamak of the Czech Technical University in Prague strives to implement up-to-date diagnostics with enhanced temporal and spatial resolution. Therefore, a novel diagnostic system of two crossed monochrome cameras Photron FASTCAM MINI UX50 was integrated into the GOLEM diagnostics. The proposed contribution will detail their novel port mounts (vertical and horizontal) at the GOLEM tokamak which have been designed so that additional optical measurements of the plasma core (e.g. plasma spectroscopy) is possible. As the main purpose of this study, we shall focus in particular on the frame rate potential which is high enough to make detection and observation of highly transient phenomena in the GOLEM plasmas possible. Progress in solving specific challenges of the ill-conditioned tomographic inversion via the algorithm optimization and testing for the GOLEM tokamak will be presented together with the first tomographic results.

Mácha et al.: Spontaneous formation of a transport barrier in helium plasma in a tokamak with circular configuration **Macha-2023-NuclFus**

Petr Mácha et al. "Spontaneous formation of a transport barrier in helium plasma in a tokamak with circular configuration". In: *Nuclear Fusion* (Aug. 2023). DOI: 10.1088/1741-4326/acf1af.

Abstract: We report on the first experimental observation of a spontaneously formed transport barrier in the tokamak with a circular configuration in helium plasmas. There was no external polarization of the plasma by electric field or other technique to form the barrier as it is typically used in tokamaks with circular plasma. In general, the transport barriers play an important role in plasma confinement especially in tokamaks with divertor configuration. In our experiments, we clearly observe distinct characteristics of a transport barrier, including a steep gradient of the electron temperature and an enhanced radial electric field along with the change in the plasma potential, floating potential, and electron temperature fluctuation. The electron temperature and the plasma potential are obtained by a combination of the ball-pen and Langmuir probe measurements with high temporal resolution on a shot-to-shot basis. This first experimental observation of the spontaneously formed transport barrier might bring new possibilities to obtain a fusion-relevant study of the edge plasma parameters and transport in helium plasmas even on small tokamaks.

Pokorny et al.: Magnetic field simulations of the GOLEM tokamak via the NICE code **Pokorny-2023-JABS**

M. Pokorny, P. Macha, and V. Svoboda. "Magnetic field simulations of the GOLEM tokamak via the NICE code". In: *Journal of the ASB Society* (2023), pp. 26–34. DOI: 10.51337/JASB20231206003.

Abstract: In this paper, the direct and inverse equilibrium computation mode of the NICE code is put into operation for the case of the GOLEM tokamak. This enables, for the first time, simulations of GOLEM's magnetic field. The computation mode put into operation simulates the magnetohydrodynamic equilibrium of a tokamak plasma based on a given plasma position or given currents in poloidal magnetic field coils. In order to set up NICE, a virtual model of GOLEM is introduced that includes axially symmetrical approximations of GOLEM's iron core and primary transformer coils. The results of NICE simulations are compared with experimental measurements, and it is shown that NICE simulations produce plasma equilibrium configurations typical for GOLEM. Nevertheless, a more detailed validation of GOLEM's virtual model and of the results of NICE simulations is to be performed in the future.

Sarancha et al.: Remote Plasma Physics Research and Teaching by Example of Turbulence Study at the University-Scale Tokamak GOLEM **Sarancha-2023-FST**

G. Sarancha et al. "Remote Plasma Physics Research and Teaching by Example of Turbulence Study at the University-Scale Tokamak GOLEM". In: *Fusion Science and Technology* 79.4 (2023), pp. 432–445. DOI: 10.1080/15361055.2022.2148842. eprint: https://doi.org/10.1080/15361055.2022.2148842. URL: https://doi.org/10.1080/15361055.2022.2148842.

Abstract: AbstractThe university-scale tokamak GOLEM provides a unique opportunity to perform remote thermonuclear experiments [V. Svoboda, J. Fusion Energy, Vol. 38, Part 2, p. 253 (2019)]. Undergraduate plasma physics students from three universities—Moscow Institute of Physics and Technology (National Research University), RUDN University, and National Research Nuclear University MEPhI—carried out joint remote experiments to train in tokamak operation and to study topics relevant for mainstream fusion research such as plasma start-up, comparison of hydrogen versus helium plasma characteristics, electrostatic and electromagnetic turbulence, long-range correlations, etc. New observations of the long-range correlations between low-frequency (¡50 kHz) quasi-coherent electrostatic and magnetic oscillations identified as m = 2 mode with several techniques were done, as well as of the broadband (¡250 kHz) magnetic oscillations resolved in frequency and wave vector in helium and hydrogen plasmas. The presence of broadband electrostatic and broadband magnetic turbulence has also been established at the plasma edge.

Conference proceedings

Cerovsky et al.: Runaway electron studies via HXR spectroscopy at Golem, COMPASS and TCV **CerovskyECPD23**

J. Cerovsky et al. "Runaway electron studies via HXR spectroscopy at Golem, COMPASS and TCV". In: *European Conference on Plasma Diagnostics*. Rethymno, Apr. 2023. URL: `http://golem.fjfi.cvut.cz/wiki/Presentations/Conferences/ECPD/5th_Rethymno_2023/poster.pdf`.

Abstract: The research on runaway electrons in tokamaks continues to be important for safe and reliable operation of large fusion devices due to the potential risk of impact of so called runaway electron beams on plasma facing components which could cause a serious damage and lead to putting the machine out of operation. In order to investigate the properties of runaway electrons and provide useful information about their behavior under different experimental conditions (e.g. efficiency of various mitigation techniques or exploration of runaway electrons free regimes) many dedicated diagnostics has been utilized. One way of inferring features of runaway electrons is a measurement of their bremsstrahlung radiation which is generated by collisions with plasma ions or by their impact on the first wall when runaway electrons are deconfined and lost. Recently, diagnostic capabilities at GOLEM [1] were upgraded by installation of two scintillation detectors with CeBr3 crystals (1" x 1"), which were also successfully tested during the dedicated runaway electron campaigns at the COMPASS tokamak [2]. Moreover, both scintillation detectors were also installed at the TCV tokamak to extend for the first time the hard x-ray radiation diagnostics and provide an estimates of the maximal energy of runaway electrons. The aim of this contribution is to describe the diagnostic used and experimental conditions of the different devices. Additionally, illustrative examples of experiments from these three different devices are presented and acquired data by the diagnostic system for HXR spectroscopy is discussed and put into the context. The comparison with other relevant diagnostics is shown. At the GOLEM tokamak the spectroscopy system was used to observe the influence of the initial pressure of the working gas and maximal energy of HXR photons was estimated about 300 keV. On the other hand at the COMPASS tokamak [3], the data recorded in experiments focused on characterizing runaway electron beams properties and the efficiency of various mitigation techniques (e.g. graphite pellet injection). At TCV [4], the installed set of scintillation detectors proved to be useful as a source of complementary information to standard radiation diagnostics and helped to characterized generated runaway electrons beams. This contribution also briefly shows a progress in modeling the radiation transport using FLUKA [5], carried out in order to better interpret the obtained data.

Chlum et al.: Tokamak GOLEM for fusion education - chapter 14 **ChlumECPP23**

J. Chlum et al. "Tokamak GOLEM for fusion education - chapter 14". In: vol. July. Europhysics conference abstracts. 2023.

Ivanov et al.: Runaway electrons measurements by ECE on the GOLEM tokamak **IvanovECPP23**

V. Ivanov et al. "Runaway electrons measurements by ECE on the GOLEM tokamak". In: vol. July. Europhysics conference abstracts. 2023.

Master thesis

S. Malec: Compton camera for detection of hard X-rays produced on the Golem tokamak **MalecMT23**

S. Malec. "Compton camera for detection of hard X-rays produced on the Golem tokamak". Master Thesis. 2023. URL: `http://golem.fjfi.cvut.cz/wiki/Presentations/Students/MasterThesis/23MalecStepan.pdf`.

Abstract: This master's thesis deals with the creation of a Compton camera to detect hard X-rays on the Golem tokamak. First, simple simulations demonstrating the functionality of a single- and two-sensor Compton camera are introduced. The thesis further describes the correction of sub- mitted AdvaPix Timepix3 detectors to a phenomenon called timewalk and to cali- bration to determine the depth of interactions in sensors. The main result is that a single-sensor Compton camera with a CdTe 2 mm thick sensor shows the best results.

Bachelor projects

Jan Buryanec: Stabilizace proudu plazmatem na tokamaku Golem **Buryanec-2023-BachProj**

Jan Buryanec. "Stabilizace proudu plazmatem na tokamaku Golem". Bachelor project. 2023. URL: http://golem.fjfi.cvut.cz/wiki/Presentations/Students/BachelorProjects/23BuryanecJan.pdf.

Abstract: This thesis deals with the stabilization of plasma current on tokamak GOLEM. In the theoretical part, the nuclear fusion and the realization of a fusion reactor in the terrestrial environment is presented. Next, the technologies used on tokamak GOLEM are described and a research of present generation of plasma current and its possible improvements via the implementation of the KEPCO am- plifier on the transformer core are done. In the next part, the laboratory table-top experiment simulating the generation of a plasma current is constructed together with its numerical simulations. For simplification, the vacuum discharge was used. After the table-top experiment proved the simulations right, the calculations for one KEPCO are done and then, the sole implementation for tokamak GOLEM. In the end, the testing of a stabilization of current for a given implementation is made and then, the discussion of a number of KEPCO amplifiers and its effects is done.

M. Vanakova: Studium oscilací magnetického pole na tokamaku Golem **Vanakova-2023-BachProj**

M. Vanakova. "Studium oscilací magnetického pole na tokamaku Golem". Bachelor project. 2023. URL: http://golem.fjfi.cvut.cz/wiki/Presentations/Students/BachelorProjects/23VanakovaMarie.pdf.

Abstract: This bachelor's thesis deals with tokamak magnetic field configuration. It focuses on the poloidal magnetic field, which was studied on the GOLEM tokamak. It also presents the safety factor, a parameter defining tokamak magnetic field properties and characterising particular discharge. The poloidal magnetic field was measured by means of an array of sixteen Mirnov coils for several tokamak discharges with various plasma edge safety factor values. Measured data was analysed by statistical methods: Fast Fourier Transformation and Cross-correlation analysis. The presence of magnetic field instabilities (magnetic islands) was observed.

High School Students' Professional Activities

M. Pokorný: Měření a simulace polohy plazmatu na tokamaku GOLEM **pokorSOC23**

M. Pokorný. "Měření a simulace polohy plazmatu na tokamaku GOLEM". High School Students' Professional Activities SOČ. 2023. URL: http://golem.fjfi.cvut.cz/wiki/Presentations/Students/HighSchoolActivities/23PokornyPolohaPlazmatu.pdf.

Abstract: The first part of this work focuses on plasma position measurement, the second on its simulation. In the first part, we compare all available plasma position diagnostics at the GOLEM (CTU FNSPE) tokamak, i.e., Mirnov coils, a ball-pen probe, and a high-speed camera. Mirnov coils and high-speed camera data were mostly in accord; the plasma boundary is more clearly defined in the case of Mirnov coils, the camera registers visible plasma radiation in the order of 1 mm beyond the real plasma boundary. Ball-pen probe and camera data mostly weren't in accord; the ball-pen probe is effective only in the case of local plasma boundary measurement. On the basis of our comparison we recommend: Mirnov coils usage is appropriate when conducting a detailed plasma position analysis, ball-pen probe usage is appropriate for local measurements, and high-speed camera usage is appropriate for quick but imprecise measurements. In the second part of the work, we put into operation the static inverse and static direct regimes of the NICE code (B. Faugeras, 2020) for the GOLEM tokamak. For this intent, a virtual GOLEM model is created, which makes use of the toroidally symmetrical iron core model presented in (T. Markovič, 2013). It is shown, on the basis of measurement and NICE simulation comparison, that the value of magnetic induction running through the real and virtual iron cores differs by a factor of approximately 2. Regimes that have been put into operation are illustrated with concrete simulations, and it is shown that their results are in accordance with typical GOLEM plasma configurations. For quick and easy usage of these regimes, a graphical user interface is created.

Miscellaneous

Unofficial articles (without GOLEM cooperation/authors)