TOKAMAK GOLEM FOR FUSION EDUCATION CHAPTER 5

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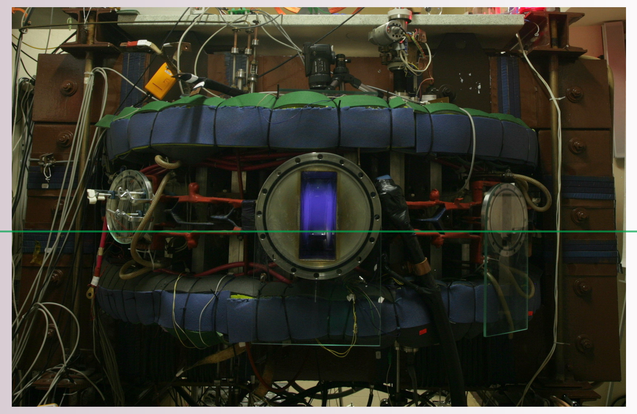
The GOLEM Tokamak

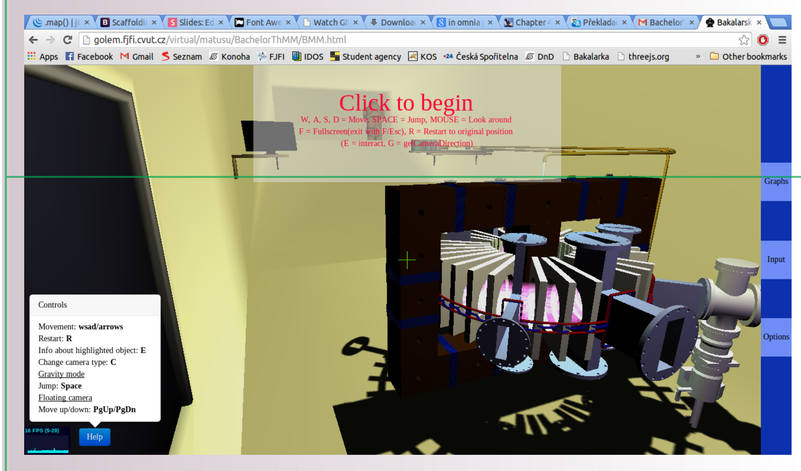


- Parameters: $B_t < 0.5$ T, $I_p < 8$ kA, pulse length < 15 ms
- An educational device for domestic as well as for foreign students via remote participation/handling
- Subject of several Bachelor's degree projects and Master's degree theses each year.
- At present used in an experimental laboratory course in the basic physics curriculum. Students become familiar with probe measurements, data analysis and basic tokamak diagnostics.

Software Reconstruction

- Operating software of the GOLEM tokamak was completely rewritten to make it more secure and accessible for students.
- It includes task control to avoid running two conflicting processes and hardware resource control to enable concurrent access to the same hardware resource.
- Implemented a server–client model with a task queue. Tasks run in parallel if possible.
- Clients can be implemented in many ways (command-line, web app, GUI etc.).
- Written mainly in Python, tracked by the Git revision system.
- Students can easily clone the repository and implement their own changes.

Virtual Model



Virtual model of the GOLEM tokamak accessed via a web browser

- Helping with presentation of the tokamak.
- Model is loaded via a web browser.
- Written mainly in WebGL and THREE.js.
- Contains a Python script to visualize users' own data (e.g. magnetic field).

Acknowledgment

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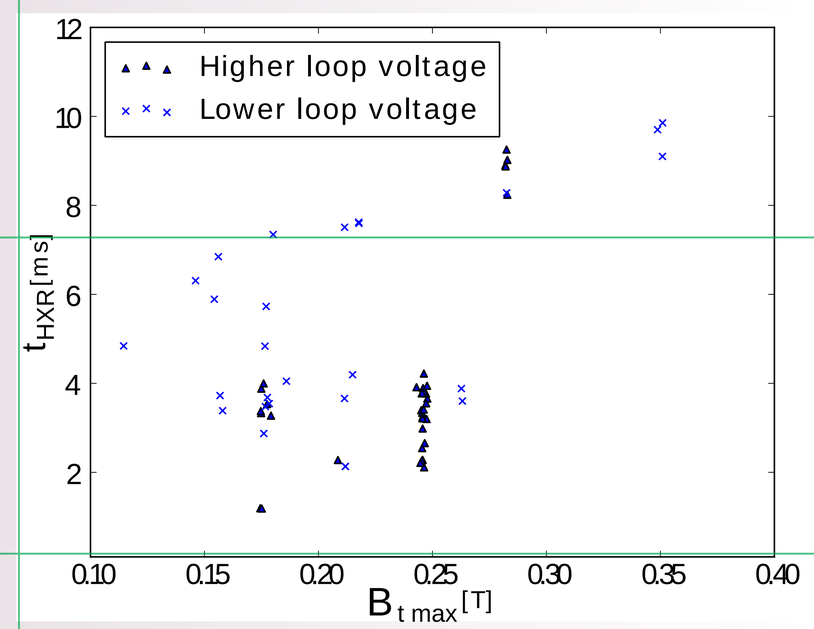
Runaway Electrons

- Production of runaway electrons (RE) is usually significant due to the high loop voltage in the GOLEM tokamak.
- HXR induced by impact of the RE with the plasma limiter (inside the vessel) are measured by a scintillation detector.
- Dependence of HXR emission on toroidal magnetic field was observed.
- With lower fields HXR emission was observed namely few milliseconds after the breakdown and the discharge was not affected much.
- With higher fields strong emission was detected just before the end of the discharge and it seemed that the RE beam carries the majority of the plasma current before the emission.



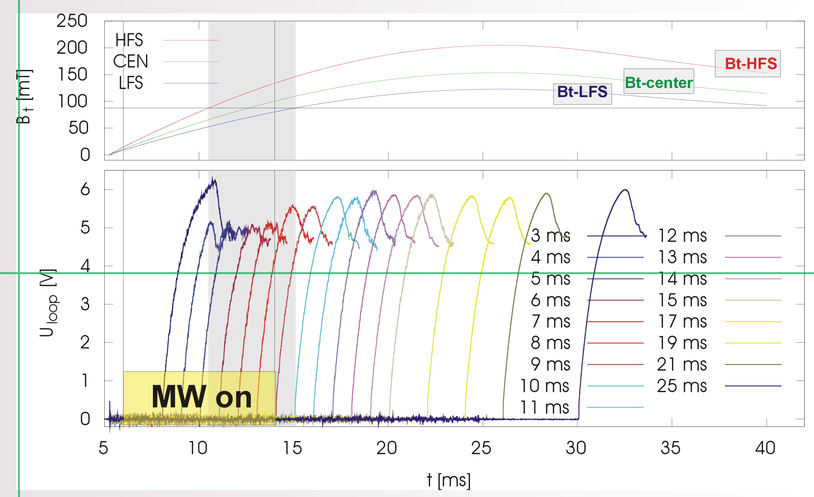
Correlation of the magnetic field and the delay between breakdown and the HXR signal beginning

Microwave Pre-ionization

- MW generator $f = 2.45$ GHz, $P_{MW} = 1.5$ kW, switched on $t_{MWon} = 6 - 14$ ms.
- Electron cyclotron resonance layer ($ECR = 87.5$ mT) inside the vessel $t_{ECR} = 11 - 15$ ms (shadowed region).
- Time delay between start of the toroidal mag. field and loop voltage changed shot to shot from 3 to 30 ms.
- Breakdown cannot be achieved without MW for the presented shots.

Results:

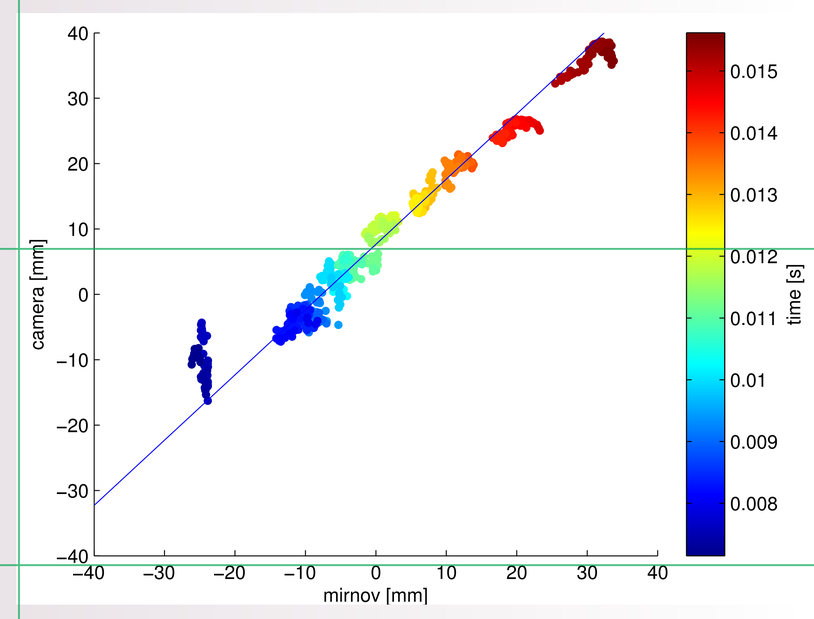
- Minimum breakdown voltage drops to 5 V during ECR inside the vessel.
- Breakdown also achieved when MW were already switched off.
- It implies the ECR plasma is confined much longer inside the vessel than expected ($t_{exp} \sim 1$ ms).



Top: Temporal evolution of the toroidal magnetic field at the High and Low Field Sides of the GOLEM vessel.
Bottom: Temporal evolution of the loop voltage at the start up phase in a series of discharges (#13493 – #13518).

Vertical Plasma Position Estimated From Fast Camera

- A visible light fast camera can be used for estimating the vertical plasma position.
- Signal from the fast camera is analyzed using two methods – fitting the signal by a Gaussian curve and calculation the center of mass of the signal.
- Both methods give similar results, but the latter was used in the correlations as it is faster.
- Comparison of the standard method for estimating the vertical position of plasma (Mirnov coils) and fast camera signal analysis was done for over 20 shots.
- Both resulting signals were strongly correlated. Only in a few shots the correlation was corrupted due to vertical plasma stabilization, which was not taken into account for processing the signal from Mirnov coils.



Correlation of the vertical plasma position from Mirnov coils and the visible light fast camera for shot #12377

Contact us

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References

[1] L. Kocmanova, Runaway electrons in the tokamak and their detection, Master Thesis at FNSPE, CTU , 2012

[2] H. Dreicer, Electron and ion runaway in a fully ionized gas, Physical Review, 1959