Former tokamak CASTOR becomes remotely controllable GOLEM at the Czech Technical University in Prague

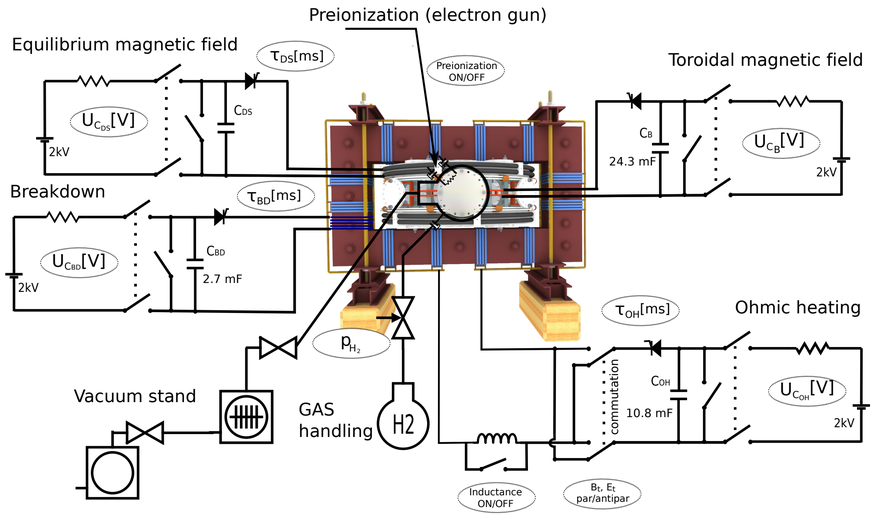
V. Svoboda[1], G. Pokol[3], D. I. Réfy[3], J. Stöckel[2], G. Vondrášek[1]

[1] Faculty of Nuclear Sciences and Physical Engineering CTU Prague, CZ-115 19, Czech Republic.
[2] Institute of Plasma Physics AS CR, CZ-182 21 Prague, Czech Republic.
[3] BME NTI, Association EURATOM-HAS, H-1111 Budapest, Hungary.

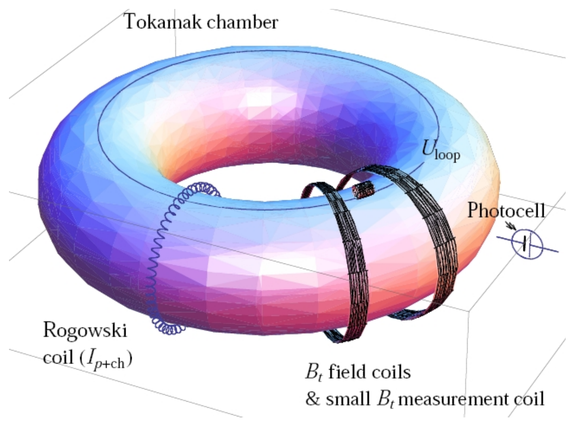
Introduction

The CASTOR tokamak, which has been operated for 30 years at the IPP Prague was moved to the Czech Technical University in Prague and became an educational device for domestic as well as for foreign students, via remote participation/handling. The reinstalled tokamak ($R = 0.4$ m, $a = 0.085$ m), now baptized as GOLEM, operates currently at modest range of parameters, $B_t < 0.8$ T, $I_p < 8$ kA, discharge duration ≈ 13 ms, and with a limited set of diagnostics. This facility will be offered to the FUSENET (the 7th FWP European Fusion Education Network) as a (remote) practica experiment.

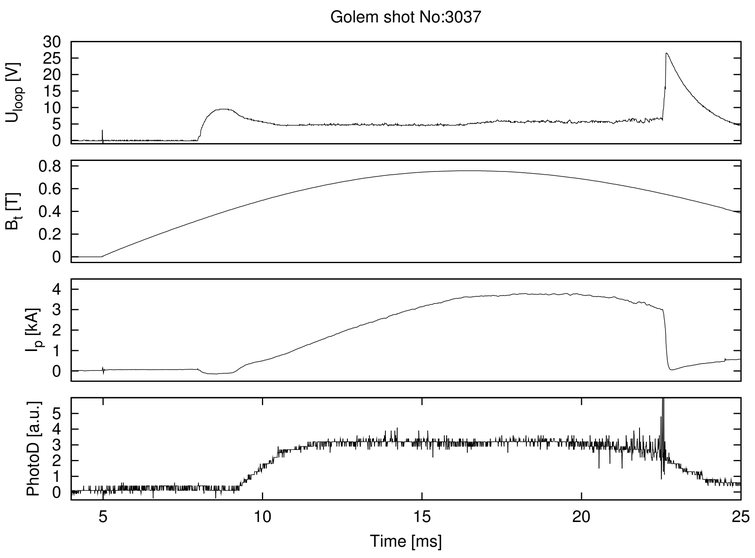
Experimental setup



Basic DAS system



Evolution of a typical Golem discharge.

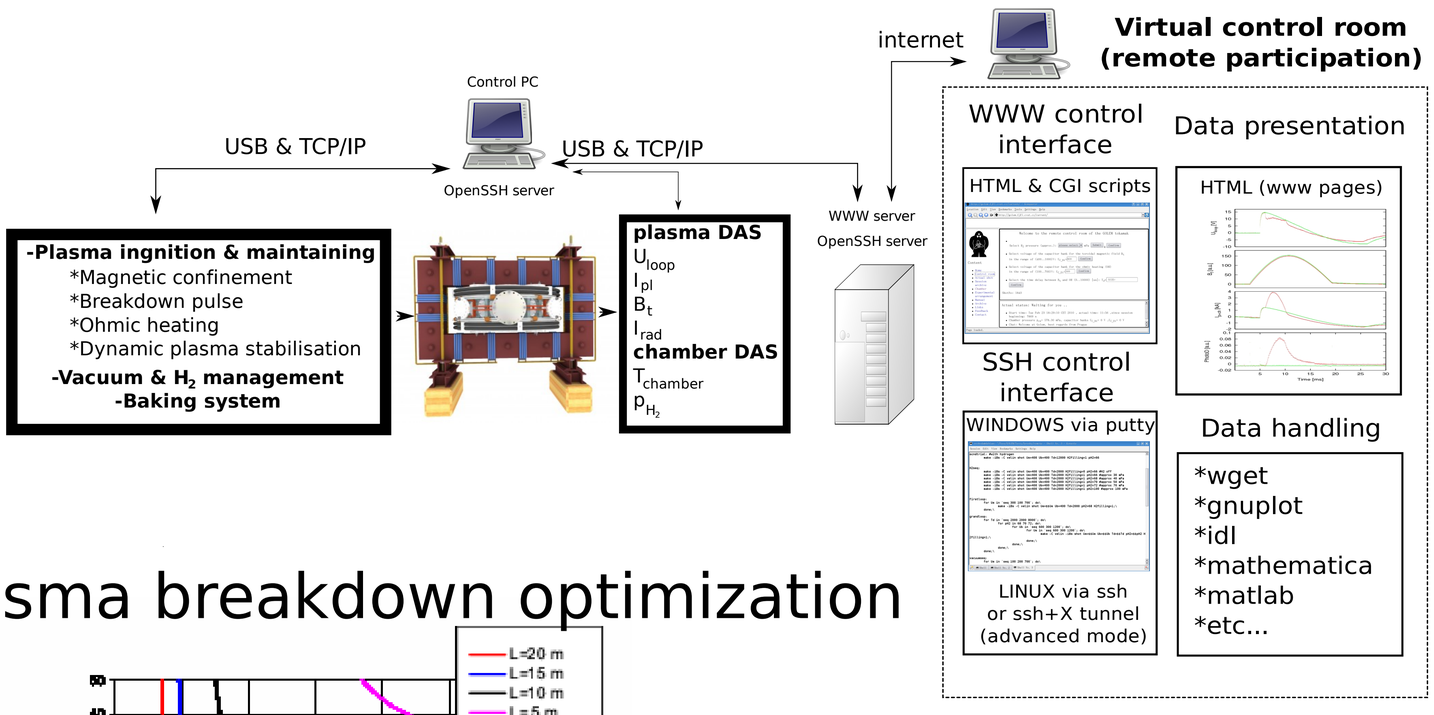


- The breakdown occurs at the toroidal magnetic field $B_t \approx 0.4$ T.
- The loop voltage at the breakdown is ~ 10 V and it decreases to ≈ 5 V.
- The plasma current reaches the value $I_p \approx 4$ kA.
- The central electron temperature can be estimated from the plasma resistivity as $T_e \approx 80$ eV.
- The safety factor at the plasma edge is about $q(a) \approx 15$.
- **It is interesting to note that this relatively long and stable discharge is achieved without any external vertical magnetic field.**

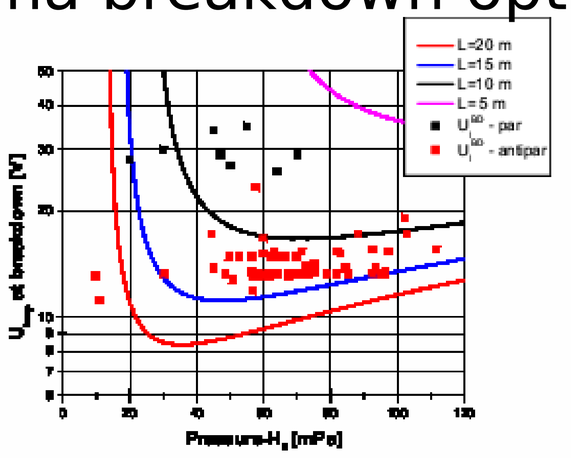
Possible studies

- Determination of vacuum chamber parameters: chamber resistivity R_{ch} and inductance L_{ch}, that can be deduced from "vacuum shots".
- Basic plasma analysis from data acquisition system (Loop voltage U_{loop}, time derivative of magnetic field $\frac{dB_t}{dt}$, time derivative of both the chamber and plasma current $\frac{dI_{pl+ch}}{dt}$, determining plasma time length ΔT_{pl}, magnetic field B_t and plasma current I_{pl}.
- Evaluation of basic plasma parameters: central electron temperature T_e, edge safety factor q_e and plasma heating power P_{OH}
- Various types of plasma breakdown studies can be performed: i) w/o preionization jet, ii) effect of parallel or antiparallel orientation of toroidal magnetic field B_t with respect to toroidal electric field E_t and iii) an effect of short (≈ 6 ms) breakdown E_{BD} pulse to the plasma formation, iv) time τ_{BD} and τ_{OH} delays optimalization of plasma formation and finally v) effect of the working gas presure p_{H_2}.
- Plasma position studies with the help of a Mirnov coils set and a linear set of 20 bolometers.
- Dynamic plasma position stabilization with an equilibrium magnetic field generated in the vertical magnetic field coils.

Remote handling operation



Plasma breakdown optimization



The theoretical curves for the minimum breakdown voltage are overplotted. These curves are calculated according the expression

$$U_{min}^{BD} = \frac{0.099\ p}{\ln(0.00375\ p\ L_{con})} \cdot 2\pi r \qquad \text{[V, mPa, m]} \qquad (1)$$

which is derived assuming that the ionization length L_{ion} is equal to the connection length L_{con}. The ionization length is $L_{ion} = 1/\alpha$, where α is the first Townsend coefficient in molecular hydrogen. The connection length strongly depends on the stray vertical magnetic field B_{vert}, $L_{con} \sim 1/B_{vert}$.

- Loop voltage at the breakdown is significantly lower, when the direction of the plasma current is anti-parallel to the field lines of the toroidal magnetic field.
- It is seen that at the anti-parallel orientation the experimental point (red symbols) correspond to the connection length ~ 15 m., while for the parallel orientation the corresponding connection length is ~ 7 m. One component of the vertical magnetic field is generated by the current in the vacuum vessel and its direction depends on the orientation of this current.
- The vertical magnetic field from the vessel current probably "compensate" any other stray vertical magnetic fields for the anti-parallel orientation, while the vertical field is "amplified" for the parallel orientation.
- Therefore, the connection length and consequently the breakdown voltage depend on the plasma current orientation.

Conclusion

- GOLEM is a university-type of an experimental facility, which is exploited for practical training of students. Students are acquainted with basics of tokamak operation, data processing and evaluation of some plasma parameters.
- Repetition rate of plasma discharges is quite high (one shot in $\approx 2-3$ minutes), therefore scans of discharge parameters can be easily performed in a couple of teaching hours.
- The unique feature of the GOLEM tokamak is its capability to be handled remotely via standard Internet. Such remote operation has been already successfully performed with several foreign universities in Hungary, Belgium, Costa Rica and with a summer school in Poland.
- Further upgrade of GOLEM is envisaged in a near future. In particular, the number of data acquisition channels will significantly increase. This will allow to exploit more advanced plasma diagnostics, such as the microwave interferometer, various electric and magnetic probes, etc.
- Wide range of measurement tasks enables the setting up of different level student measurement programs.
- A practicum can be organized for students in a general physics MSc program with the aim of demonstrating the basic tokamak operation and getting them acquainted with plasma properties and operational limits.
- Series of measurements can be compiled for students specializing in fusion plasma physics with more complex tasks, like advanced breakdown studies and plasma position control.
- Practica at the GOLEM tokamak could be appealing for universities not only for being a cheap alternative of building their own demonstration devices. Such a remote measurement also develops soft competences, like communication skills, interpretation skills, process planning and team work.