

# PART 1: The GOLEM Experiment

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## 1 About GOLEM Tokamak

### 1.1 A bit of History

Tokamak GOLEM - one of the smallest and oldest tokamaks - today is intended mainly for education and training of students at the Czech Technical University in Prague. It is also known for being the smallest tokamak in the world with the largest control room - the tokamak can be controlled remotely via the Internet.

Tokamak GOLEM was built parallel with two more tokamaks - T-2 and TM-2 - in beginning of 1960s under name TM-1 (M stands for small in Russian - "Mali") at Kurchatov Institute in Moscow. Those tokamaks were first ones with stable plasma, that makes GOLEM tokamak an old timer among the tokamaks. TM-1 had went through few modifications for a different experimental goal purposes.

Mid-70s, the tokamak TM-1VCh, as that was GOLEM's name at the time, had been transferred to the Institute of Plasma Physics in Prague where it is renamed to CASTOR (abbreviation from Czech Academy of Science TORus). Here it served full three decades for plasma physics studies and diagnostic testing, mostly electrostatic probes.

Finally, with the installation of the larger tokamak COMPASS at Institute of Plasma Physics in Prague around 2007, CASTOR is moved to Faculty of Nuclear Science and Physical Engineering (Czech Technical University) under its current name GOLEM.

### 1.2 Tokamak - a Basic Principle

A significant part of the tokamak principle is similar to the principle of electrical transformer - to drive the current through the plasma ring (as a secondary windings of a transform), we use a current in many turns of the central solenoid (primary windings of a transformer) changing in time. From the Faraday law, the changing current creates an electrical field that drives the current in the plasma. The existence of the current is a key to the tokamak successful confinement, but it is also a source of the numerous problems called instabilities.

Second indispensable part of tokamak are poloidally oriented and toroidally distributed coils for generation of a toroidal magnetic field. Running current through the coils produces magnet field by Ampere law. The toroidal field is confining the plasma inside the tokamak vessel, which has ring-like or doughnut shape.

For the rest, you will need to listen lectures carefully ;)

### 1.3 GOLEM Main Parameters

GOLEM major radius (radius of ring from its center to the center of the vessel) is  $R = 0.4$  m and minor radius (radius of plasma in the vessel) is  $a = 0.085$  m. Toroidal magnetic field  $B_t$  has strength up to 0.5 T and plasma current  $I_p$  can reach almost 4 kA. The discharge length  $t$  is typically not longer

than 15 ms. Electron densities  $n_e$  are of order of  $10^{18} \text{ m}^{-3}$ , while electron temperatures  $T_e$  can reach few tens of the electron-volts<sup>1</sup>.

## 2 Operation of GOLEM

### 2.1 General Information

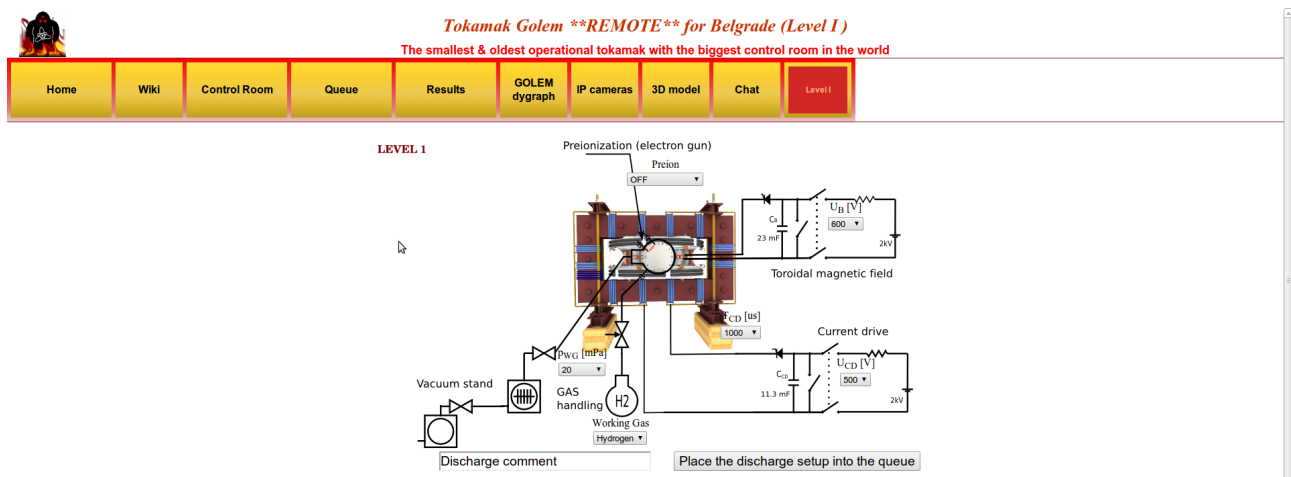
Web of GOLEM: <http://golem.fjfi.cvut.cz> Access to GOLEM database: <http://golem.fjfi.cvut.cz/shots/0/> (shows the last executed shot)

### 2.2 GOLEM Operation for Dummies (G4D)

Before you start doing this, note that tokamak is not always available for shooting outside the Dani Fuzije@NS, so please make sure that Vojtech knows about you running it. On the Workshop do not do random discharges, wait for the confirmation from your supervisor and/or Milos!

*Step 1:* go to the link <http://golem.fjfi.cvut.cz/NoviSad> (note the burning GOLEM sign on the top left :D).

*Step 2:* Click on the '**Control Room**' button at the upper menu, now you get the following picture:



*Step 3:* WHAT CAN BE MODIFIED?

a) **Preion** = Preionization OFF (default), Top el. gun, ECRH assisted:

Choosing type of preionization. Even though Option 'OFF' is a default, use 'Top el. gun', as this one you assure that there will be breakdown to initiate ionization of gas for creating plasma! Option 'ECRH assisted' is not functioning at the moment! While it is possible to create plasma with 'OFF', it is a gambling and could be a waste of discharge thus time!

b) **p<sub>WG</sub> [mPa]** = Pressure in the vacuum vessel before the discharge from 1 to 100 with some steps, with 20 as default:

Even though 20 mPa is default, pressure should be set to lower as possible.

c) **Working Gas** → Hydrogen (default), Helium:

Simply setting the working gas both are available, but maybe better to stay with the H due to the long time needed to get pure He-plasma.

<sup>1</sup>1 eV ≈ 11600 K or 11300 °C

d)  $U_B$  [V] = Voltage going through the capacitor charging the toroidal field (TF) coils from 50 to 1100 with step of 50 V, where 600 is default:

This defines the strength of the toroidal magnetic field  $B_t$  higher  $U_B$ , higher  $B_t$ .

e)  $U_{CD}$  [V] = Voltage going through the capacitor charging the central solenoid from 50 to 700 with step of 50 V, where 500 is default:

This defines the strength of the plasma current  $I_p$  higher  $U_{CD}$ , higher  $I_p$ .

f)  $T_{CD}$  [ $\mu$ s] = Delay time of the central solenoid charging relative to TF coils charging from 500 to 20000 with step of 500, where 1000 is default:

This defines delay time when the central solenoid will start to be charged relative to the starting time of charging the toroidal field coils (which is always 5 ms!!!). Higher this time, higher is the  $B_{tor}$  at the breakdown to have maximum  $B_{tor}$  at the breakdown  $T_{CD}$  has to be set on 19000!

g) **DISCHARGE COMMENT:**

**DO NOT FORGET ABOUT THIS ONE!!!** It is very very (2 times very is not a mistake!) important to write down why or what are you doing in this discharge. It is good for making difference after the experiments so maybe write your name or something funny to make the discharge even more special ;)

*Step 4:* Give a discharge to an execution waiting list, by pressing the '**Place the discharge setup into the queue**', after that you check is your discharge in the queue, by clicking on the '**Queue**' button. Here you should see all discharges in the queue and their statuses.

Once you check that there is a discharge for you you go to the '**IP cameras**' button, where the live streaming of the GOLEM tokamak hall is shown. There are two screens one camera (left hand side) shows you the room with tokamak, where first blue rotating beacon light will sign the start of the discharge process and finally red rotating beacon light alarms that there is only 10 seconds until the discharge and everybody (if anybody is still in the room) should leave the room immediately; second camera (right hand side) is inside the tokamak and you will see the 'Top electron gun' for preionization (if set ON) and after some time a strong flash is seen which is the discharge!

**\*\*\* CONGRATULATIONS YOU JUST MADE A TOKAMAK DISCHARGE \*\*\***

## 2.3 Experimental plan

Driven by the experience from the last year, the plan is to do a scan over few input parameters. This will probably be  $U_B$ ,  $U_{CD}$ ,  $T_{CD}$  and  $p_{WG}$ . The exact details will be given at the beginning of the experimental part of the Workshop.

### 3 Getting the Data

After some time you can finally go to the '**Results**' button and check what is there. There should be the list of all discharges done during the session (if any). Now you can click on the **discharge number (in 'Global ShotNo' column)** and see the data. After clicking on the **discharge number**, the new page is open with few graphs on the top.

Now a little bit of physics, just to briefly explain the meaning of the presented graphs:

- **Loop voltage U**: is practically the toroidal electric field, if U is divided by  $2R$  ( $R=0.4\text{m}$ ). It introduces the charge separation (thus plasma creation) at the beginning of the discharge. It is measured with the single loop along the tokamak's toroidal direction.
- **Toroidal mag. field  $B_t$** : keeps plasma in the vessel. It is measured with the pick-up coils near toroidal field coils.
- **Plasma current  $I_p$** : induced current in plasma, as a secondary winding. It adds an poloidal component of the magnetic field. It is measured with the Rogowski coil spirally arranged loop in the poloidal direction. N.B. As the Rogowski coil is outside the vessel it measures both, plasma current and current going through the vessel.
- **Visible &  $H_\alpha$** : radiation detected by the photocells - one without (Visible) and one with filter around  $656\text{ nm}$  ( $H_\alpha$ ).
- **Electron density  $n_e$** : is measured with the interferometer - a device that measures phase change of the wave injected in the plasma. N.B. The measurement is integrated along the whole wave path through the plasma.

Under the graphs is the list of all available data for the shot one can simply download .txt files and analyse them in any tool you find appropriate: e.g. MatLab, Python, Origin, Excel, etc.