Influence of the working gas pressure on the plasma current and on the confinement time on GOLEM tokamak

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Abstract

In order to achieve nuclear fusion by magnetic confinement, it is necessary to maximise the plasma confinement time. Moreover, the current produced by the movement of charged particles is used to create the poloidal magnetic field in a tokamak. One must then find a way to maximise these parameters in order to have good performances. In this report, we propose to examine how to find good parameters for the plasma. Using GOLEM tokamak and its system to perform discharges remotely, we studied the influence of the working gas pressure on the plasma current and on the plasma confinement time. We also examined the whole plasma resistance regarding those results.

1. Introduction

Future ambitions for tokamaks are to reach high confinement so that a high ratio between the power supplied and the power produced by the Deuterium/Tritium fusion reaction can be achieved. The success of one magnetized plasma operation is given by the Lawson criterion. It defines a threshold for which the deuterium-tritium reaction is auto sufficient.

Even if a good power ratio can be achieved without reaching ignition, one wants to maximize the above parameters when it comes to evaluating the success of magnetic confinement.

To confine the plasma in a tokamak, a system of magnetic coils is used for the particles to follow the magnetic field lines. As the field is not homogeneous, the plasma particles are subject to a vertical $\vec{B} \times \vec{\nabla} B$ drift. To compensate for this drift and keep the plasma particles confined, one must add a poloidal magnetic field so the field lines become helicoidal. This poloidal field is generated directly by the plasma current I_p, following Ampere's law. One then finds the higher the plasma current, the better the plasma confinement. There are different methods to generate I_p such as induction (via a transformer), waves (Neutral Beam Injection), and via the bootstrap current, which comes from banana orbits that get untrapped. Another important parameter we study in the present report is the plasma confinement time τ_c, which appears directly in the Lawson criterion.

During this practical week, we used the remote control of GOLEM tokamak to examine the variation of the plasma current and of the plasma confinement time. Even though this tokamak is small in comparison to ITER, it enables us to have a first insight into the parameters necessary for achieving nuclear fusion. Among the different parameters we could change at each experiment, we decided to focus on the influence of the working gas pressure. Note that we exclusively used hydrogen and never helium. The results on GOLEM are quite the same for the two gases, as shown in this recent study [1], and the former one is much cheaper.

2. Presentation of the GOLEM device

The GOLEM tokamak is a rather small device, with a major radius $R = 0,4$ m, and a minor radius $a = 0,085$ m. It operates with a range of toroidal magnetic field $B_t < 0,8$ T, and a plasma current $I_p < 8$ kA. It is possible to proceed with experiment completely remotely, via Internet access.

To proceed a discharge on the GOLEM tokamak, the first step is to evacuate the chamber to make the vacuum inside. Then comes the pre-discharge phase : one must charge the capacitors and fill the chamber with the working gas (Hydrogen or Helium, although we all used Hydrogen for our discharges). This first step leads to the pre-ionization of the gas, with an electron gun. After this preparatory phase, the coils must be switched on in order to put a toroidal magnetic field, which will confine the plasma inside the device. One must also create a toroidal electric field for neutral gas to ionize and to breakdown into a plasma. Moreover, this toroidal electric field also enables the plasma to heat. Once one reaches all theses steps, the GOLEM device is ready for a discharge. The repetition rates on the GOLEM tokamak make a discharge possible every 2-3 minutes approximately. [2] [3]

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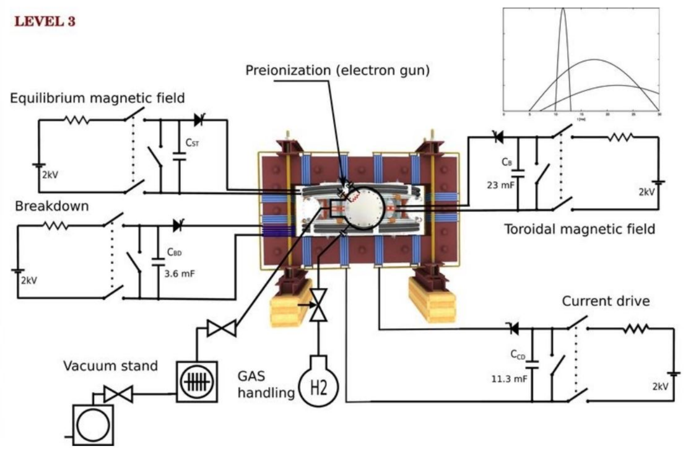

Figure 1: Different electronic circuits involved in GOLEM tokamak, [2]

To capture key plasma parameters during a discharge, the GOLEM tokamak comes with different diagnostics. A single loop surrounds the tranformer core and measures the loop voltage U_{loop}. Some Rogowki coils surround the tokamak chamber and measures the total current (sum of the plasma current and the chamber current $I_p + I_{ch}$). Another coils measures the toroidal magnetic field B_T. Finally, a photocell is placed in front of a glass part of the tokamak and detects the plasma radiation in the visible light spectrum. An example of the values we get for a typical discharge comes in FIGURE 3.

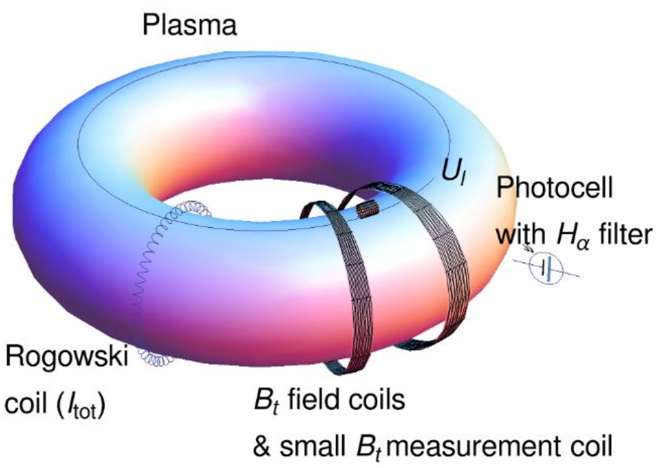

Figure 2: Basic diagnostics on GOLEM tokamak

To access more advanced plasma parameters, the tokamak diagnostics have been improved. Microwaves are used to measure the electron density inside the plasma. The waves interact with the magnetized plasma and interferometry detects the signal that passed through the plasma, relatively to the reference signal. High Speed VIS Cameras, with frames up to 1200 fps and a time resolution 40 kHz have also been installed perpendicularly to the plasma column. This enables VIS tomography. A visible light spectrometer is based on the cameras. [4]

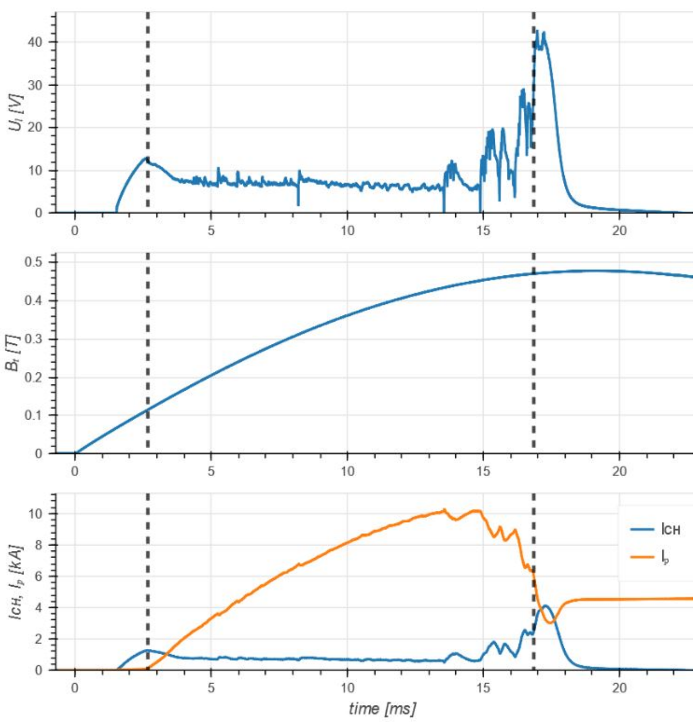

Figure 3: Typical values for U_{loop}, B_T and I_{ch} for the discharge number 35659 we performed

3. Experimental results

We began our work by performing a few discharges on the GOLEM tokamak to see what was the influence of the working gas pressure on the plasma current. We used by default parameters for GOLEM tokamak : $U_B =$ 600V, $U_{CD} = 400$V, no time delay for the loop voltage and we made the working gas pressure vary. Surprisingly, we found two maxima for the plasma current : one at $16mPa$ and one at $6mPa$. However, when we tried to reproduce the experiment to see whether these results were constant, we did not find again such high values for I_p and τ_c (see FIG. 4)

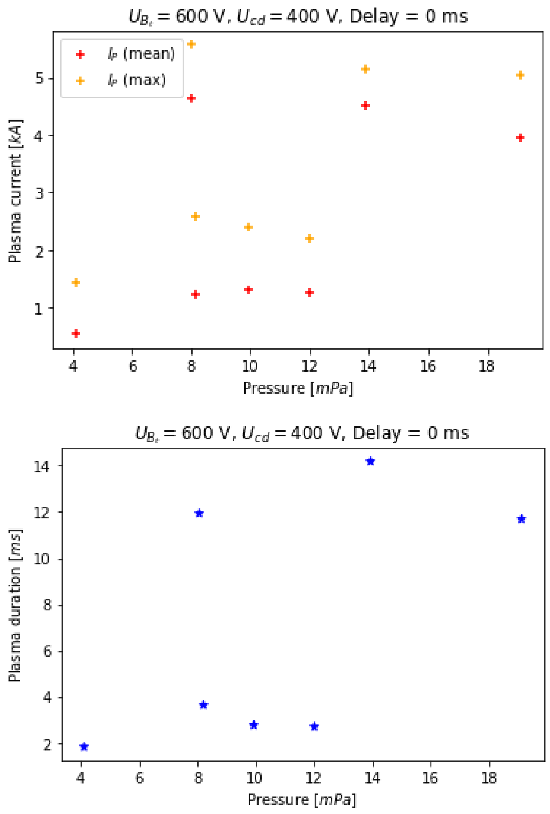

Figure 4: Results obtained with the first series of discharges, U_B = 600V, U_{CD} = 400V, no time delay for U_{loop}

In order to minimize the variability of the results, we discussed with the other group working on GOLEM plasma current and decided to change other parameters according to their conclusions. We then worked with B_T = 800 V and U_{CD} = 700 V. The time-delay for the loop voltage still remains null in the following experiments.

We show a global tendency for the plasma current to increase with the working gas pressure.

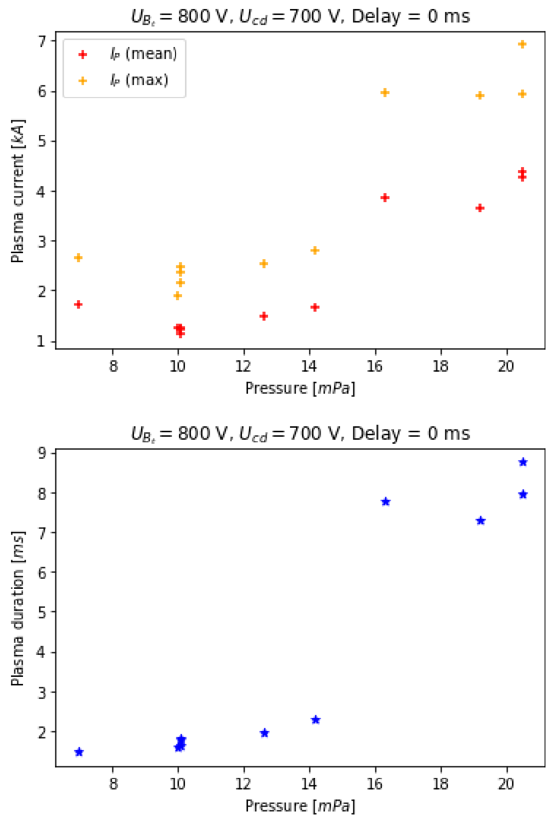

Figure 5: Results obtained with the first series of discharges, U_B = 800V, U_{CD} = 700V, no time delay for U_{loop}

To analyse this phenomenon, we got interested in the global plasma resistivity. We used the following formula :

$$R_{plasma} = \frac{2\pi R}{\pi a^2} \cdot \eta = \frac{U_{loop}}{I_p}$$

Where $R = 0,4$ m is the major radius of the GOLEM tokamak, and $a = 0,085$ m is the minor radius. η is the plasma resistivity. Here are the results we have for the last series of shots.

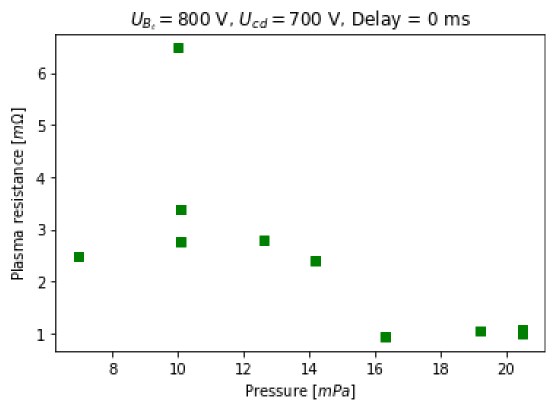

Figure 6: Results obtained with the first series of discharges, U_B = 800V, U_{CD} = 700V, no time delay for U_{loop}

We observe the total plasma resistance presents a peak at 6 mPa.

Finally, we examined our results in the light of the Paschen law. We plotted the breakdow voltage versus the pressure. The Paschen's law is the following :

$$V_{breakdown} = \frac{Bpd}{C + \ln(pd)}$$

Where B and C are constant values depending on the gas, p the gas pressure and d the distance between electrodes. We often express C depending of the parameter A, the link being $C = \ln(A) - \ln(\ln(1 + \frac{1}{\gamma}))$. γ is the efficiency coefficient between the electron and ion current. For H_2, tabulated values give $A = 5\ torr^{-1} \cdot cm^{-1}$, and $B = 5\ V \cdot torr^{-1} \cdot cm^{-1}$. We expected the graph of $V_{breakdown}$ as a function of the gas pressure to show a minimum at low pressures and then increase, however, that is not what we eventually got. Such a graph is shown in Figure 7.

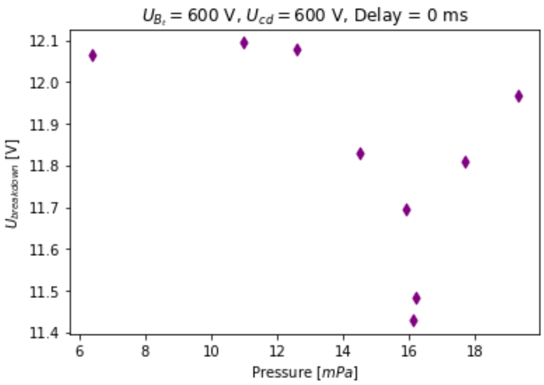

Figure 7: Example of an experimental plot of the breakdown voltage as a function of the gas pressure

4. Discussion

Although this work regarding the influence of the working gas pressure on the confinement time and plasma current of a discharge seemed promising at first, we did not show a significant link between these parameters. Nevertheless, some colleagues of us worked on other parameters and found an interesting relation.

5. Acknowledgments

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References

[1] V Svoboda, A Dvornova, R Dejarnac, M Prochazka, S Zaprianov, R Akhmethanov, M Bogdanova, M Dimitrova, Zh Dimitrov, O Grover, L Hlavata, K Ivanov, K Kruglov, P Marinova, P Masherov, A Mogulkin, J Mlynar, J Stockel, and A Volynets. Remote operation of the GOLEM tokamak with hydrogen and helium plasmas. *Journal of Physics: Conference Series*, 768:012002, oct 2016.

[2] Vojtech Svoboda. Introduction to the tokamak operation(golem specific). 2021.

[3] V. Svoboda, B. Huang, J. Mlynář, G.I. Pokol, J. Stöckel, and G. Vondrášek. Multi-mode remote participation on the golem tokamak. *Fusion Engineering and Design*, 86(6):1310–1314, 2011. Proceedings of the 26th Symposium of Fusion Technology (SOFT-26).

[4] GOMTRAIC team. Golem training course https://sites.google.com/site/gomtraic/tokamak-golem.