Chapter 1

The GOLEM tokamak

1.1 Introduction

During my staying at Prague I participated SUMTRAIC 2010. During this summerschool one day was devoted to perform experiments on the GOLEM tokamak. Hence it is worthwhile to include some data of that campaign and to extract some basic information from it.

1.2 History

The history of GOLEM goes back to the early sixties. At that time GOLEM was called TM–1 and was located in the Kurchatov Institute in Moscow, former Sovjet–Union. This tokamak was actually one of the first working fusion machines based on the tokamak concept. In 1975 TM–1 moved to the IPP in Prague, former Czechoslovakia, and was named TM–1 MH. In 1985 it was renamed to CASTOR which stands for Czech Academy of Sciences TORus. CASTOR was intensively used as a fusion research machine from 1977 till 2006. In 2004 the tokamak COMPASS located at Culham, UK, was offered to IPP Prague. The offer was accepted and CASTOR needed to make place for this new tokamak COMPASS. As a consequence CASTOR was offered to the Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University. Hence CASTOR moved to his new location and was renamed GOLEM. This rather strange name originates from a jewish legend because the Technical University is located in the jewish part of Prague. A golem is some kind of creature made of mud by the jewish rabbi Löwe that was brought alive. The golem was intended to serve and protect the jewish people as it did. In that context GOLEM tokamak can be considered as serving students and scientists in the learning process about fusion. The GOLEM tokamak is nowadays not so important anymore because it is rather small and only a limited selection of diagnostics are available (see section 1.4). However it is rather unique in his kind because it can be operated by remote controll. Any one who would want to perform an experiment can operate GOLEM from his/her location. The only thing what needs to be done is to request an experiment to the operater and to connect to the internet. One can chose own input parameters and immediately after the shot the data appear online.

1.3 Short technical overview

The GOLEM tokamak is a small tokamak with main parameters:

- Major radius $R_0 = 0.4\,\mathrm{m}$
- Minor radius $a = 0.1\,\mathrm{m}$
- Radial position of the limiter $r = 0.085\,\mathrm{m}$

- Hydrogen plasma

In figure 1.1 one can find a engineering scheme of GOLEM. For more technical details and how GOLEM operates we refer to the GOLEM webpage [1] and the instruction guide for the tokamak [2].

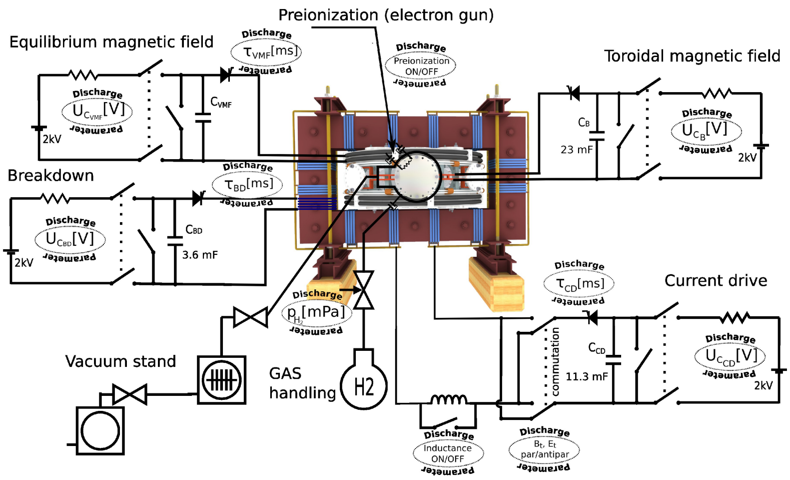

Figure 1.1: Engineering scheme of GOLEM [1].

1.4 Diagnostics

Due to limited funding and working staff only a limited amount of diagnostics are available. In figure 1.2 one can find a overview of the available diagnostics. There is:

- a single loop around the transformer core to measure the loop voltage U_{loop}.
- a Rogowski coil, surrounding the tokamak chamber to measure the sum of the plasma and chamber current $I_{\text{p+ch}}$.
- a small pick–up coil placed on the tokamak chamber to measure the toroidal magnetic field B_t.
- a photocell facing a glass port of the tokamak to measure the plasma radiation in the visible part of the spectra.

We refer again to [1] and [2] for more information about the diagnostics. All the obtained experimental data from these diagnostics are digitized by a sampling frequency of 100 kHz and stored by a PC. Later on the data can be accessed via the online archive (see [3]).

1.5 Experiments and results

1.5.1 Goal of the experiment

The data obtained from the plasma discharge on GOLEM are used to determine the **energy confinement time** τ for different plasma parameters. We have choosen to determine the energy confinement time because it is a very important fusion parameter. We have not discussed this parameter in the chapters about COMPASS therefore a short derivation is given here [2, 4].

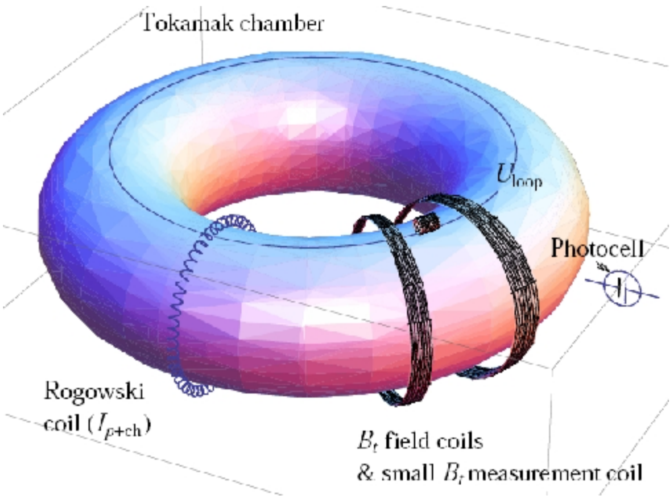

Figure 1.2: Diagnostics available on GOLEM [1].

Plasma heating power

The only heating source for the plasma in the GOLEM tokamak is current driven Ohmic heating. The power of this heating mechanism is simply given by:

$$P_{OH}(t) = U_{loop}(t)I_{pl}(t) \tag{1.1}$$

with U_{loop} the loop–voltage and I_{pl} the plasma current which both can be read from the online database.

Central electron temperature

It can be shown that the specific resistivity of the plasma is only dependent on the central electron temperature T_e and the effective charge of the plasma Z_{eff}. On can find that:

$$T_e(t) = \left(\frac{R_0}{r^2}\frac{8Z_{eff}}{1.544\,10^{-3}}\frac{1}{R(t)}\right)^{\frac{2}{3}} \tag{1.2}$$

$$\approx 80\left(\frac{I_{pl}(t)[kA]}{U_{loop}(t)[V]}\right)^{\frac{2}{3}} \tag{1.3}$$

where in (1.2) the estimation $Z_{eff} = 2.5$ is taken, R_0 and r see section 1.3 and $R(t)$ is the plasma resistance. In (1.3) the numerical values are filled in such that T_e is expressed in units eV.

Plasma density

The plasma density n is estimated based on the ideal gas law because of the lack of real density measurement techniques on GOLEM. Hence remark that this is only a crude estimation for the plasma density.

$$n = \frac{2p_{ch}}{k_B T_{ch}} \tag{1.4}$$

with p_{ch} the chamber pressure and $k_B T_{ch}$ the thermal energy corresponding with the chamber temperature T_{ch}.

Plasma energy

With the expression for the central electron temperature (see equation (1.3)) and for the plasma density (see equation (1.4)) one can calculate the total energy content of the plasma $W(t)$:

$$W(t) = \frac{nk_BT_e(t)V}{3} \tag{1.5}$$

with $V = \pi r^2 2\pi R_0$ the plasma volume.

Energy confinement time

We now have an expression for the energy content of the plasma $W(t)$ at certain moment of time (equation (1.5)) and for the plasma heating power $P_{OH}(t)$ (equation (1.1)). The energy confinement time τ is given by the ratio of these parameters when the energy content is maximal. We define the maximum of $W(t)$ as W_{max} which is reached at a time t_{max}. With this moment of time corresponds $P_{OH}(t_{max}) = P_{W_{max}}$. We thus have:

$$\tau = \frac{W_{max}}{P_{W_{max}}} \tag{1.6}$$

The energy confinement time is an indication for the time scale on which the plasma loses its energy. The longer τ, the better the plasma is confined. Towards fusion reactors with a energy yield it is important to have a energy confinement time as high as possible.

1.5.2 Results

Energy confinement time in function of inserted gas pressure

In this section one examines the relation between the energy confinement time τ and the pressure of the inserted H_2–gas p_{H_2}. The pressure was increased with steps of roughly 5 mPa startting from 15 mPa till 50 mPa (shots #3480–3484 and #3495–3498). In figure 1.3 one can find τ (calculated with equation (1.6)) in function of the effective pressure p_{H_2}.

One can see that τ roughly increases with increasing gas pressure. This behaviour is expected because a higher gas pressure induces a higher plasma density. As a consequence the plasma energy will be higher (equation (1.5)) and hence also the energy confinement time τ.

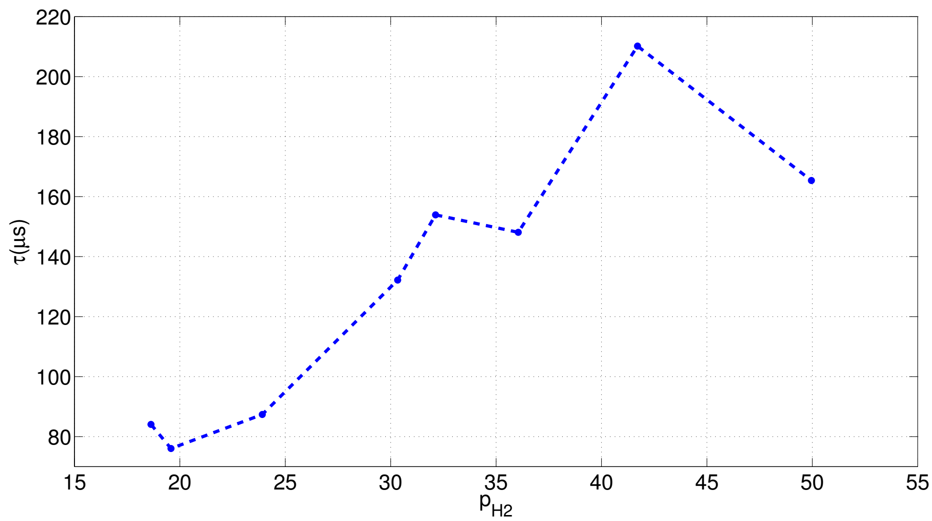

Figure 1.3: Energy confinement time τ in function of inserted gas pressure p_{H_2} .

Energy confinement time in function of applied voltage for the toroidal magnetic field U_b

An other experiments deals about the relation between τ and the applied voltage for the creation of the toroidal magnetic field U_b. During shots #3470–3474 one increase U_b with steps of 120 V starting from 720 V till the maximum of 1200 V. In figure 1.4 one can find the result.

It is clear that τ increases with increasing U_b. This is logical because a increasing voltage U_b induces an increasing toroidal magnetic field and hence the plasma becomes better confined.

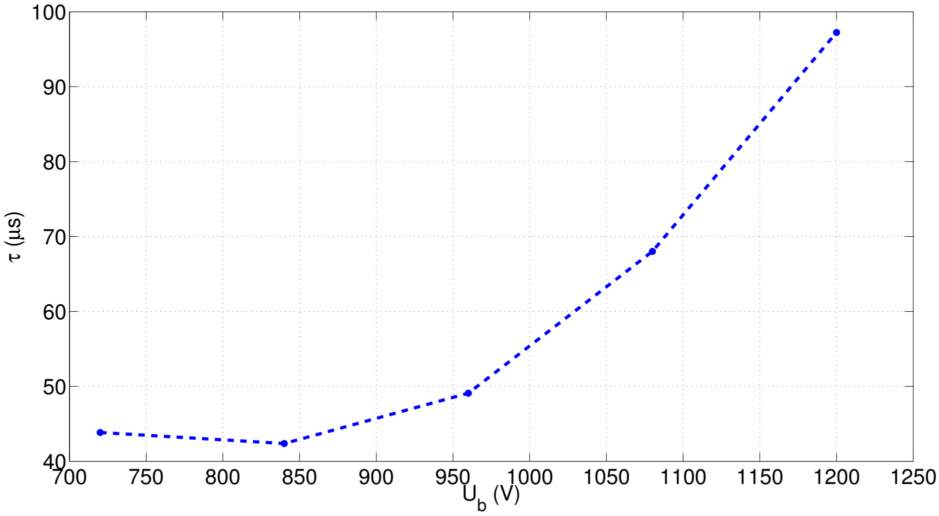

Figure 1.4: Energy confinement time τ in function of the applied voltage for the toroidal magnetic field U_b .

1.6 Conclusion

During the campaign on GOLEM a number of shots were made. A few data outputs were used to determine the energy confinement time τ, a characteristic of how good energy is confined in the plasma. One can find that τ increases with increasing inserted gas pressure and increasing toroidal magnetic field. Although only a limited variety of diagnostics are available GOLEM is of great educational importance. It can be used to demonstrate some principles of the tokamak concept. Furthermore the remote controll is very convenient to make the experiments and the data accessible for every body around the globe. On the first of December 2010 this was clearly demonstrated with the **Tokamak Global Experiment** which united 38 participants from 10 different countries to make real fusion shots [5].

Bibliography

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[5] The Tokamak Global Team, "Global tokamak experiment." http://tokamakglobal.com/, cited December 2010. 5