Experiments on Golem : Report

Written by:
Antoine MOLLARD and
Antoine MAITRALLAIN

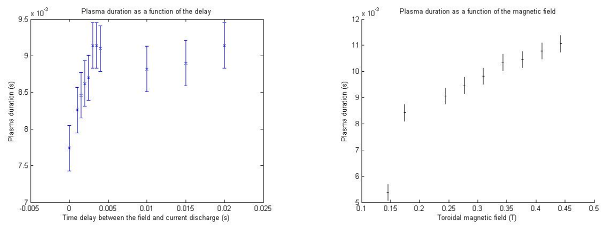
During this hands-on work, we had a chance to run experiments on Golem tokamak in Prague. The parameters that were available to change were : the type of pre-ionization, the pressure of the working gas, the time delay between the discharge which produces the toroidal magnetic field and the one that creates the toroidal current, the voltage in the coils of the toroidal field and the voltage at which the discharge that generates the plasma current occures. Regarding these parameters, we first tried to maximize the plasma duration. But before, we would like to talk about the way we obtained our measures and especially the way we obtained the error bars in all the graphics. To do so, we had a serie of 6 shots with the exact same parameters. From these discharges, we deduced (thanks to the standard deviation) the error bars :

- pressure ± 0.45mPa
- plasma duration ± 0.31ms
- mean loop voltage $\pm 0.094V$
- mean plasma current $\pm 58A$
- mean toroidal magnetic fiel $\pm 0.0014T$
- electron temperature $\pm 0.68eV$

I]Plasma duration

After each scan, we tried to evaluate the best value of the parameter we were looking at regarding the plasma duration and we would keep this value for the next experiments. First, we thought that the variations of the plasma duration regarding the time delay between the discharge which produces the toroidal magnetic field and the one that creates the toroidal current were included in the fluctuations. (In fact changing the time delay changes the value and the sens of variation at which the plasma discharge occures). That is why we chose this parameter to be 15 ms so the plasma current is existing when the magnetic field reaches its maximum and hence is quasi-stationary.

So, we can see on this plot (1a) that the plasma duration reaches a maximum and then is constant. This means that after the poloidal magnetic field (which is varying during the entire plasma discharge) reaches a certain level, then the plasma duration is quasi-constant for larger delays (when the magnetic field is quasi constant). The plasma needs a large magnetic field to have a long duration. However, the time scale of the variation of the magnetic field is really



a b

Figure 1: Plasma duration as a function of a) the delay b) the toroidal magnetic field

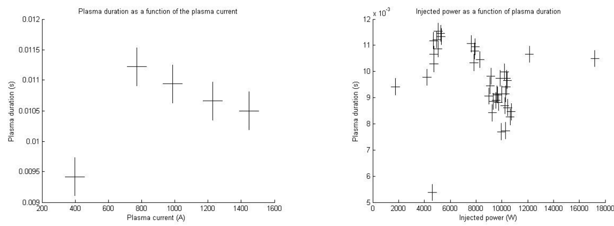
superior to the plasma duration, so we thought the more stable the magnetic field is, the longer the plasma lasts.

Then, we had a look at the value of the magnetic field at its maximum (1b). We found that for a given injected power above a certain threshold, the plasma lasts longer when the magnetic field increases. Below a certain magnetic field, we cannot create the plasma and the increasing of the plasma duration is due to the fact that the confinement of the plasma is better when the magnetic field is larger so the plasma duration is then larger.

We also measured the plasma duration as a function of the injected power(2a). From this graphic, we can identify different regimes. It is unlikely to have plasma below 4kW and the plasma duration cannot be shorter than 5 ms. We can also see that there is an optimum regime to create a plasma which is around 10kW. Above this power, the plasma duration does not increase. However we did not do so many shots in this regime during the experiments, so it's hard to conclude for this region. The way we computed the injected power is given in section 3].

We finally took into account the effect of the plasma current (2b) compared to the plasma duration. We can see on the plot that there is also a threshold effect : there is no plasma below a certain value of the current. Then, there is an optimum current for which the plasma duration is maximized and then the life time of the plasma deacreases. It is because when the plasma current becomes more important, it lasts shorter. Since the plasma duration is related to the current discharge time, the life time of the plasma becomes less important when the plasma current becomes larger. The way the plasma current is calculated is given in section 3].

The optimization of the plasma duration gave us a maximum value of 11.5 ms. For this measurement, the parameters were : a pressure of 4 mPa, a delay between the discharges that lead to the plasma current and the toroidal magnetic field of 15 ms, a voltage on the capacitors that gives the magnetic field of 1300V, a voltage on the capacitors that gives the magnetic field of 400V and pre-ionazation "Top el. gun + MW".

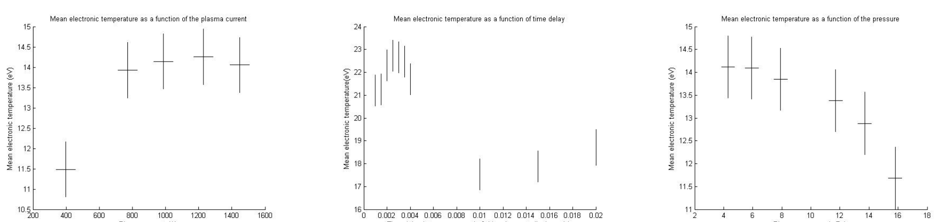


a b

Figure 2: Plasma duration as a function of a) the plasma current b) the injected power

II]Electron temperature

We also have studied the variations of the mean temperature of electrons as a function of different parameters. We paid attention to the influence of the plasma current (3a), the pressure (3c) and the time delay (3b) between the shot that triggers the magnetic field and the one that triggers the plasma current. As we can see, the mean electronic temperature is not varying with the plasma current between 800 and 1500 A. This must be due to the plasma saturation; the ionization seems indeed complete from 800 A. However, the electronic temperature is a decreasing function of the pressure: the energy given to the plasma is shared by more and more particles as we increase the pressure, so the kinetic energy of each electron, which is related to electron temperature, decreases. The figure below shows that short time delay between magnetic field and current discharges drive to high mean electronic temperatures. On short time delay tests, the magnetic field varies during the acquisition. This growth generates an electric field around the toroidal magnetic field lines and a drift velocity of ExB is directed toward the center of the plasma. We could assume that this



a b c

Figure 3: Electron temperature as a function of a) the plasma current b) the time delay c) the pressure

phenomenon tends to increase the local temperature and plasma resistance.

III] Questions

1/Total current

The offset current is due to how the electric circuit is made. The integration in time is necessary to get the signal during the entire plasma duration and the calibration factor is due to the particular diagnostic we are using.

2/Plasma current

Thanks to a vaccum shot, we can deduce the resistance and inductance of the vessel. When there is plasma in the chamber, we can model the system as 2 RL circuits in parallele and deduce the current which is really into the plasma. If we find the particular time where :

$$\frac{\partial I_c - I_p}{\partial t} = 0$$

where I_c is the current through the chamber and I_p the plasma current then the resistance of the plasma is given by $\mathrm{R}_p = R_c * \frac{I_c}{I_p}$.

We compute the chamber resistance $R_c = 0.0097\Omega$ using the vaccum shot and we find $R_p = 3.56\mathrm{m}\Omega$.

4/Injected Power

Here we use the mean values because otherwise, we would have to integrate the plasma current and the loop voltage, so it gives :

$$P_{plasma} =< U_{loop} > * < I_p >$$

where P_{plasma} is the injected power, U_{loop} is the loop voltage and $<>$ meaning the mean value.

5/Electron temperature

Using the given formula and dropping the integral using the mean values we obtain :

$$T_e = (\frac{< I_p > * R_0 * Z_{eff}}{1.13 * 10^3 * < U_{loop} > * r})^{2/3}$$

with T_e the electron temperature (eV), R_0 the major radius and a the minor radius

IV] Conclusion

As we have observed during this hands-on, the plasma life time is a function of the time delay between the discharges, the pressure, the plasma current and the toroidal magnetic field. However, the electron temperature is higher when the toroidal magnetic field is increasing than during the stationary mode. Other physical phenomenon must be implied ; unfortunately, we did not have enough time to conclude on this point. We also wanted to caracterise the plasma radius and position with respect to the magnetic field and plasma current, but again we did not have enough time.