GOLEM

Experiments on the tokamak of the Czech Technical University

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Introduction

As a result of the cooperation of the Czech Technical University (CTU) and the Budapest University of Technology and Economy (BME) we had the opportunity to make measurements on the GOLEM tokamak via internet connection. This paper summarizes our progress of work, gathered data and experiences during this time.

The tokamak

A tokamak is a certain kind of fusion reactor, in which the magnetic field confining the plasma, is generated by a system of external coils and a strong toroidal plasma current, as seen in figure 1).

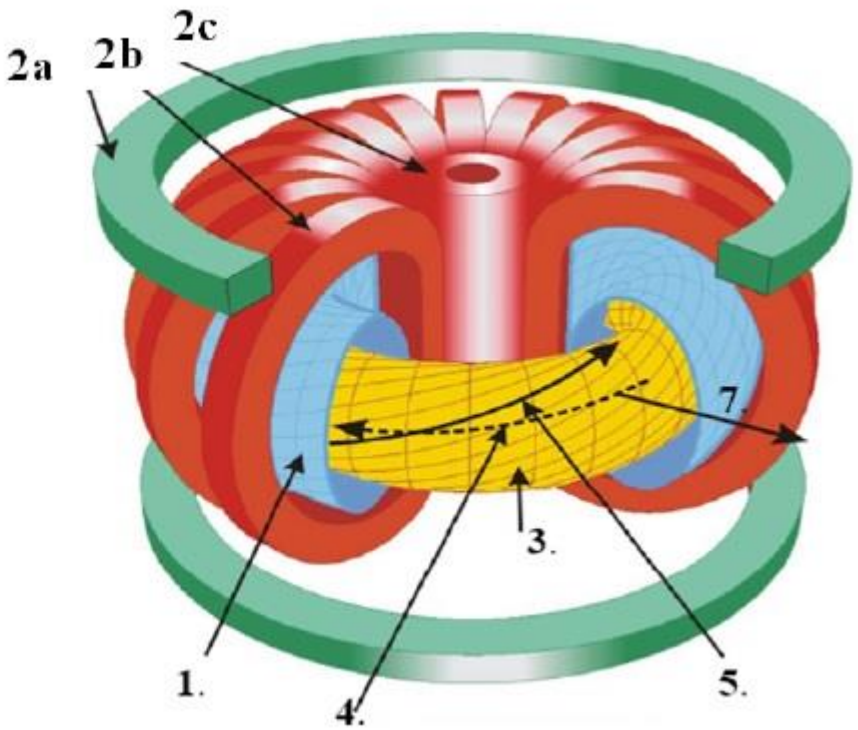


Figure 1.) 1. vacuum chamber, 2. a-c coils, 3. plasma, 4. plasma current, 5. magnetic field line, 7. radial field line

Further information on fusion and fusion reactors can be found in John Wesson's book, The Science of Jet.

During our work we could alter the toroidal magnetic and electric field, the gas pressure in the chamber, the length of the time delay between the triggers of the toroidal fields and we could turn on a preionization function in the chamber.

The equipments measuring the tokamak, provided us with data from the loop voltage, the toroidal- and the Rogowski coil and a photodiode. The chamber pressure after a shot, the chamber temperature, and the calibration factors of the previously listed datasets were also given to us.

From this information we were able to compute the following properties of the generated plasma.

Used formulas

The circuit equation of the chamber:

$$U_l = R_{ch} I_{tot}(t) + L_{ch} \frac{dI_{tot}}{dt}$$

Where U_l is the loop voltage, R_{ch} the chamber resistance, L_{ch} the inductivity of the chamber and I_{tot} the total current, computed as:

$$I_{tot}(t) = I_{ch}(t) + I_{pl}(t)$$

I_{pl} is the plasma current.

If we alter the first formula R_{ch} and L_{ch} can be easily computed with a linear fit:

$$\frac{U_l}{I_{tot}(t)} = R_{ch} + L_{ch} \frac{dI_{tot}}{dt \cdot I_{tot}(t)}$$

Using the circuit equation again:

$$U_l = R_{ch} I_{ch}(t) + L_{ch} \frac{dI_{ch}}{dt}$$

$$U_l = R_{pl} I_{pl}(t) + L_{pl} \frac{dI_{pl}}{dt}$$

,we can constuct the plasmacurrent, and with Ohm's law the plasma resistance.

After these, we can compute the ohmic heating power of the current:

$$P_{OH}(t) = R_{pl}(t) I_{pl}^2(t)$$

If we set the effective charge number to $Z_{eff} \approx 2.5$, the equation of the central electric temperature can be solved as (R_0-major plasma radius, a-minor plasma radius):

$$T_{e0}(t) = \left(\frac{R_0}{a^2} \frac{8Z_{eff}}{1544} \frac{1}{R_{pl}(t)} \right)^{2/3}$$

We can estimate the order of the electron density by (p_{ch}-chambe pressure, T_{ch}-chamber temperature, k_B-Boltzmann-constant):

$$n_{avr} = \frac{2p_{ch}}{k_B T_{ch}}$$

This is a rough estimation, since the plasma in the GOLEM is not fully ionized and the absorbtion of gases released by the wall components facing the plasma also adds to this density.

With knowledge about the electron density we can calculate the plasma energy, but this will be just as much a rough estimation as n_{avr} (V is the volume of the plasma):

$$W_{pl}(t) = V \frac{n_{avr} k_B T_{e0}(t)}{3}$$

Lastly, we can get the energy confinement time with the following formula:

$$\tau_E(t) = \frac{W_{pl}(t)}{P_{loss}(t)}$$

The managment of the data and the calculations were executed by Matlab scrits. The detailed and commented codes can be found in the appendix.

Determination of the chamber parameteres

During the experiments a part of the toroidal current flows in the vacuum chamber. For further data processing one have to determine the resistance and the conductivity of the chamber. In a vacuum shot without plasma breakdown the current measured by the Rogowski-coil flows entierly in the vessel. Using the altered circuit equation and a polinomial fit on the data of such shoots, we were able to determine the chamber parameters.

Shoot no	L_ch (T)	R_ch (Ω)
17172	9,94E-08	9,90E-03
17173	5,49E-07	9,72E-03
17171	2,95E-07	9,02E-03
17175	4,05E-07	1,25E-02
17179	7,24E-07	1,11E-02
mean	4,14E-07	1,04E-02

Table 1.) Calculated chamber parameters (fitting)

Another method is to claculate Lch at the moment when the toroidal field is switched on ($I_{tot} \approx 0$), and R_{ch} when the current reaches its maximum ($\frac{I_{tot}}{dt} \approx 0$).

Shot no	L_ch (T)	R_ch (Ω)
17172	5,85E-07	9,30E-03
17173	1,70E-06	9,80E-03
17171	8,80E-07	9,90E-03
17175	1,85E-08	9,60E-03
17179	7,41E-08	9,40E-03
mean	6,52E-07	9,60E-03

Table 2.) Calculated chamber parameters (secund method)

For further calculation we choose the means given by the first method, since it seems to be more accurate.

Measured and calculated results

With the data given by the server and the calculations discussed in previosly we were able to calculate the seeked parameters of the plasma breakdown. Our results are summarized in the following tables.

Shot no	U_cd (V)	p preset (Pa)	U_lmax (V)	p_ch (Pa)
17174	400		1,95E+01	1,18E-02
17176	350		1,75E+01	1,16E-02
17177	300		1,46E+01	1,15E-02
17178	200		1,08E+01	1,15E-02
17187	700	0,02	2,82E+01	2,68E-02
17188	700	0,03	2,81E+01	3,77E-02
17190	700	0,04	1,94E+01	4,59E-02
17191	700	0,035	2,69E+01	4,17E-02
17192	600	0,035	2,22E+01	4,33E-02
17194	500	0,035	1,97E+01	2,75E-02
17199	600	0,03	1,70E+01	4,22E-02
17200	600	0,02	2,31E+01	2,67E-02
17201	700	0,04	2,83E+01	2,08E-02
17202	700	0,045	2,46E+01	5,44E-02
17203	700	0,03	2,39E+01	4,06E-02
17204	700	0,02	2,46E+01	3,02E-02
17205	700	0,016	2,50E+01	2,59E-02
17206	700	0,014	2,59E+01	2,41E-02

Table 3.) Preseted data, the loop voltage and the chamber pressure of shots with plasma breakdown

Shot no	I_p (A)	t_dc (s)	P_OH (J/s)	Te0 (ev)	n_avg (1/m3)	W_pl (eV)	τ (s)
17174	1,75E+03	6,50E-03	1,71E+04	3,08E+01	5,01E+18	2,93E+18	3,28E-04
17176	1,74E+03	7,40E-03	1,52E+04	3,44E+01	4,93E+18	3,22E+18	3,28E-04
17177	1,32E+03	6,80E-03	9,90E+03	3,01E+01	4,91E+18	2,81E+18	1,80E-01
17178	7,74E+02	5,70E-03	4,89E+03	2,17E+01	4,91E+18	2,03E+18	3,91E-02
17187	2,65E+03	7,20E-03	4,49E+04	2,75E+01	1,14E+19	5,97E+18	4,70E-03
17188	2,42E+03	6,80E-03	4,08E+04	2,63E+01	1,61E+19	8,04E+18	9,20E-03
17190	2,70E+02	2,00E-03	5,02E+03	4,87E+00	1,96E+19	1,81E+18	1,54E-04
17191	2,07E+03	6,40E-03	3,53E+04	2,21E+01	1,78E+19	7,48E+18	2,84E-04
17192	1,29E+03	4,80E-03	1,90E+04	1,66E+01	1,85E+19	5,84E+18	4,30E-03
17194	1,38E+03	5,50E-03	1,70E+04	2,11E+01	1,17E+19	4,70E+18	4,60E-03
17199	2,47E+02	1,50E-03	3,97E+03	5,04E+00	1,80E+19	1,72E+18	1,00E-03
17200	1,83E+03	6,20E-03	2,65E+04	2,21E+01	1,08E+19	4,52E+18	3,11E-04
17201	2,73E+03	7,40E-03	4,63E+04	2,87E+01	8,38E+18	4,57E+18	4,14E-04
17202	1,40E+03	4,90E-03	2,35E+04	1,63E+01	2,19E+19	6,77E+18	1,52E-02
17203	2,11E+03	6,70E-03	3,56E+04	2,21E+01	1,63E+19	6,87E+18	1,10E-03
17204	2,48E+03	7,20E-03	4,19E+04	2,91E+01	1,22E+19	6,73E+18	2,80E-03
17205	2,60E+03	7,50E-03	4,34E+04	2,61E+01	1,04E+19	5,17E+18	1,93E-04
17206	2,77E+03	7,60E-03	4,59E+04	2,73E+01	9,69E+18	5,04E+18	1,59E-04

Table 4.) Further parametes of the succesful plasma breakdowns

Shot no	U_cd (V)	p preset (Pa)	U_lmax (V)	p_ch (Pa)
17171	500		4,4177	1,25E-02
17172	100		5,59E+00	1,21E-02
17173	300		9,0167	1,18E-02
17175	400		10,3125	1,16E-02
17179	200		6,1768	1,15E-02
17180	250	0,01	7,5934	1,37E-02
17189	700	0,04	19,5911	9,09E-02
17193	500	0,035	14,2669	6,61E-02
17195	400	0,035	11,944	4,45E-02
17196	300	0,035	9,1107	6,31E-02
17197	300	0,03	8,869	2,72E-02
17198	400	0,03	11,7291	4,70E-02

Table 5.) Shots without plasma breakdown

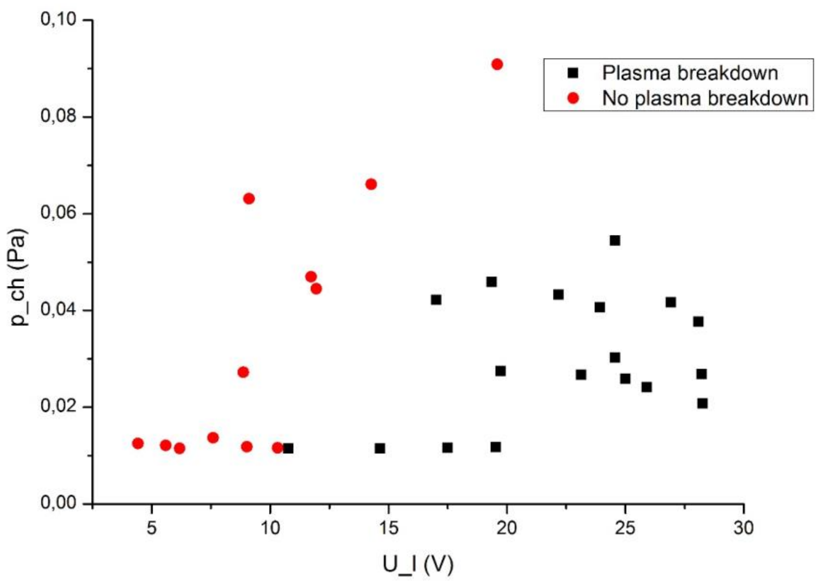
17171-17179 Vacuum shots

17180-17206 Shots with H-gas

17203-17206 q=2 disruption experiments

The preionization was turned on at shot 17176.

For further investigation of the plasma breakdowns, we ploted the chamber pressure against the maximum of the loop voltage.



Fiure 2.) Chamber pressure as the function of maximume loop voltage in different shots

The red dots simbolise the shots without, and the black ones the shots with plasma breakdown. It is clear, that there is a line which separate the two as we expected with a slope with $m \approx 4 \cdot 10^{-3} Pa/V$.

Representation of the results

Experimentation with the alteration of the gas pressure was rather unsuccesful, since the measured chamber pressure seemed to change diregarding what we intented, so we relied more upon the alteration of the current drive voltage.

To demostrate the difference between the raw data collected by the detectors and the refined data, we included a couple of diagrams produced by the ’master1’ script.

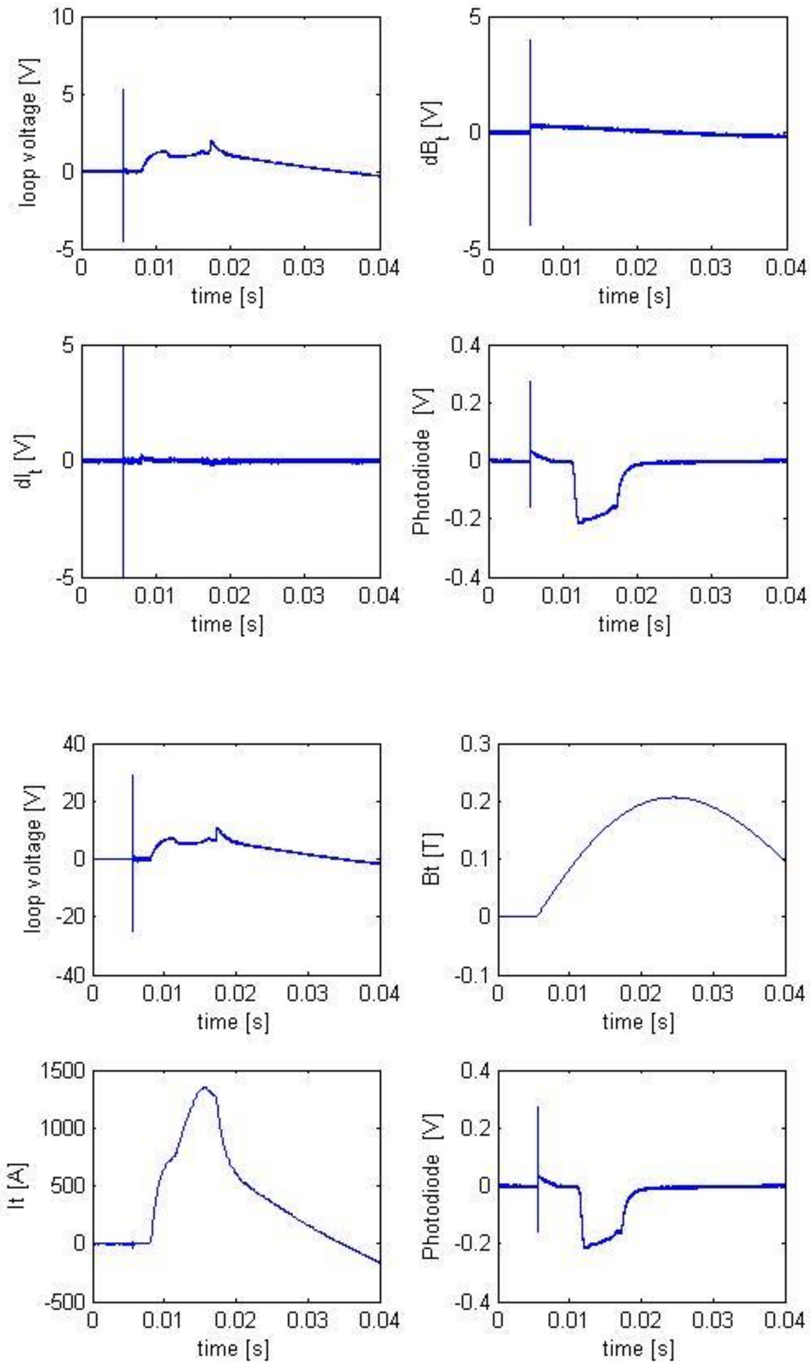


Figure 3-4.) Results of the ’master1.m’ scipt on the data of shot 17178

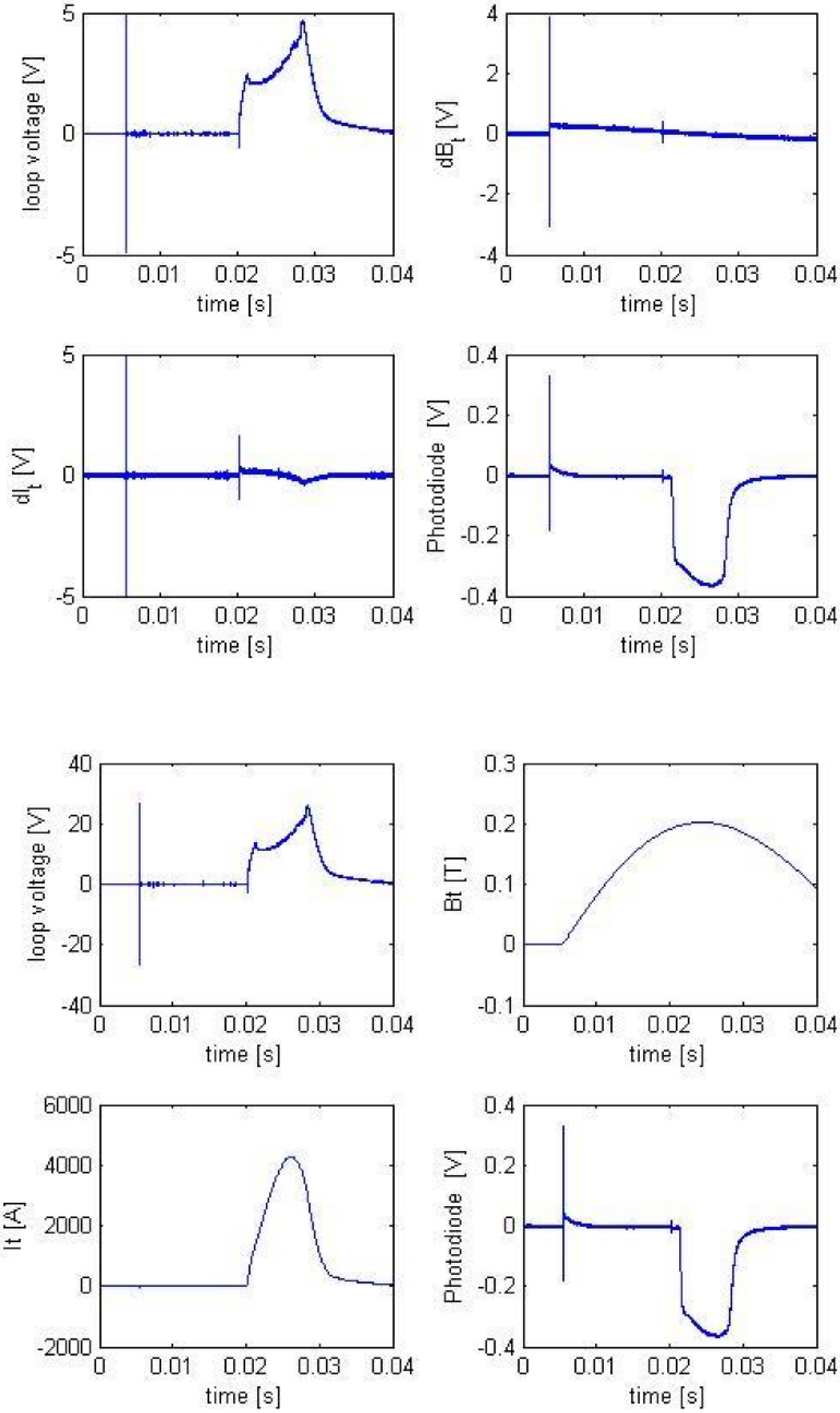


Figure 5-6.) Results of the 'master1.m' scipt on the data of shot 17206

As it can be seen the first step of dataprocessing is calibration and the elimination of the false values produced by the electronics.

The graps in the next part represent the calculated parameters as a function of time to illustrate their characteristics during the plasma breakdown.

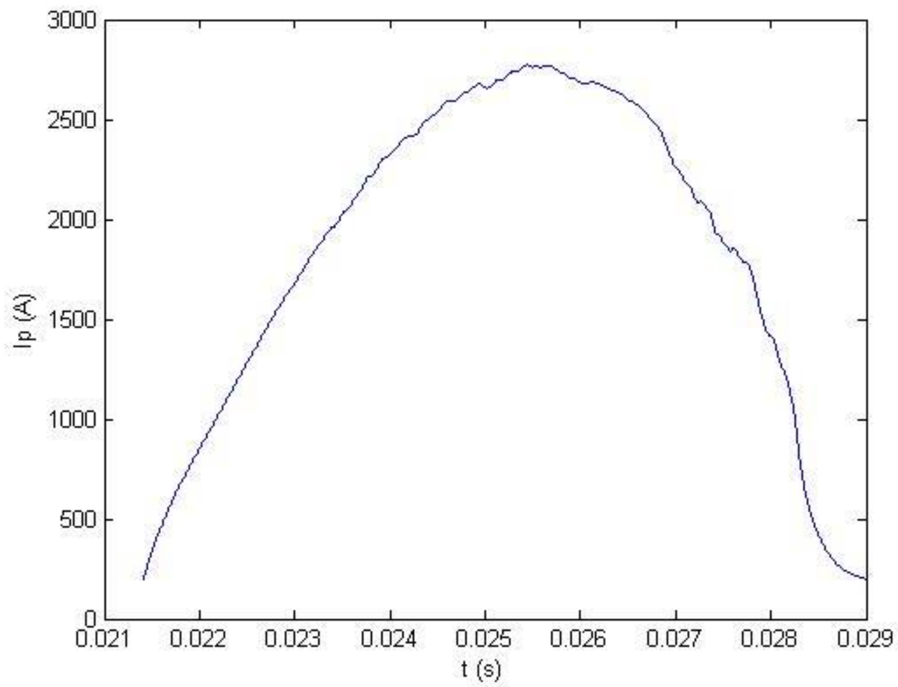


Figure 7.) Highest plasma current and discharge time in shot 17206

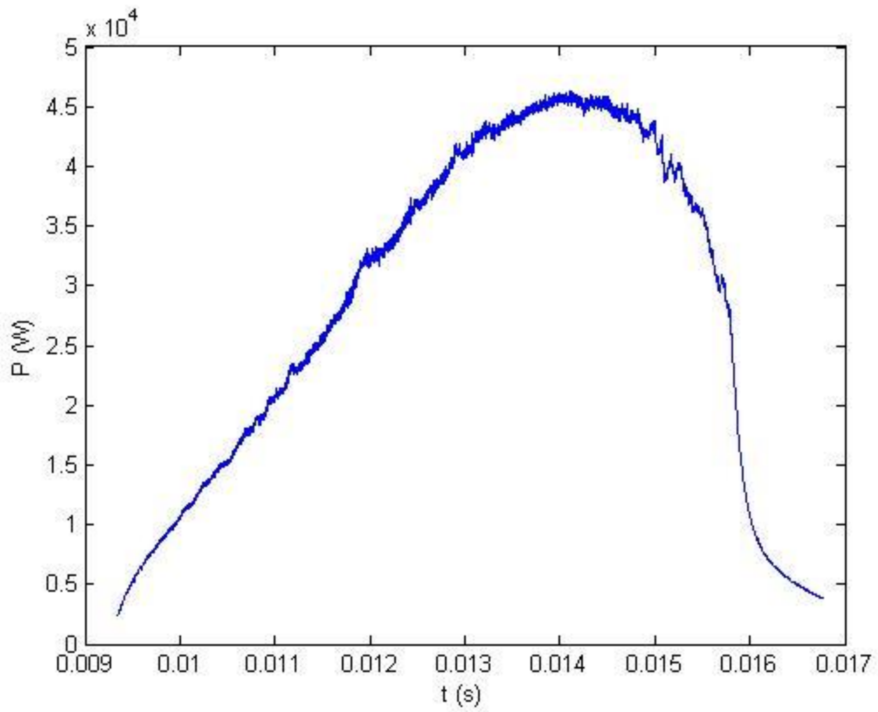


Figure 8.) Highest plasma heating power in shot 17201

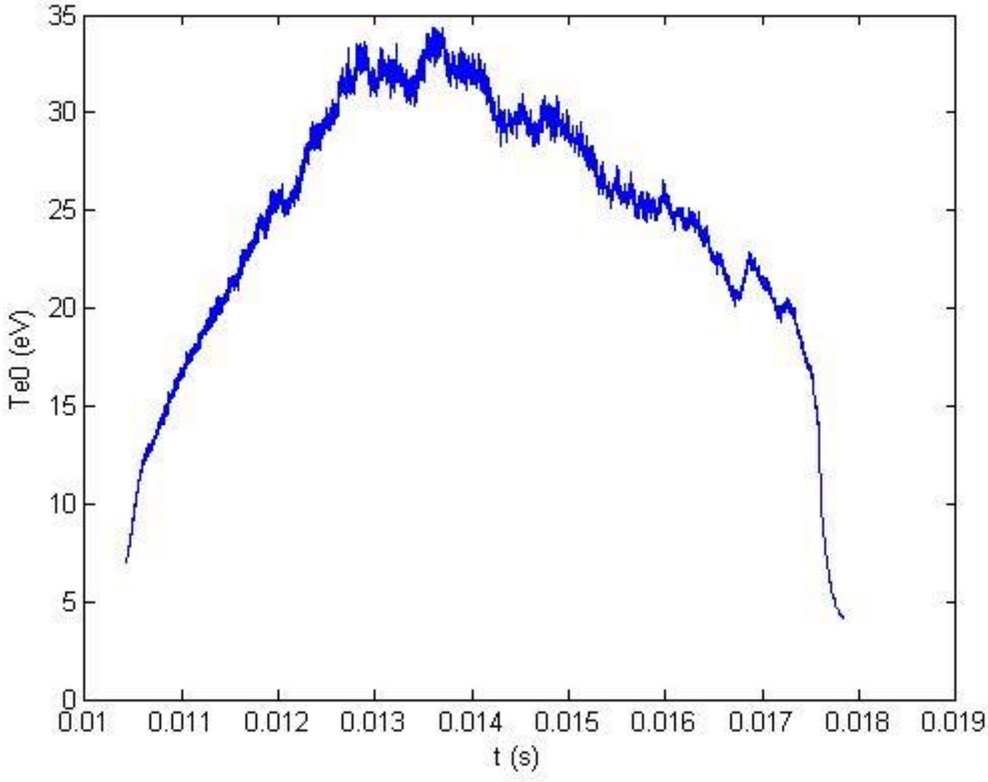


Figure 9.) Highest central electron temperature in shot 17176

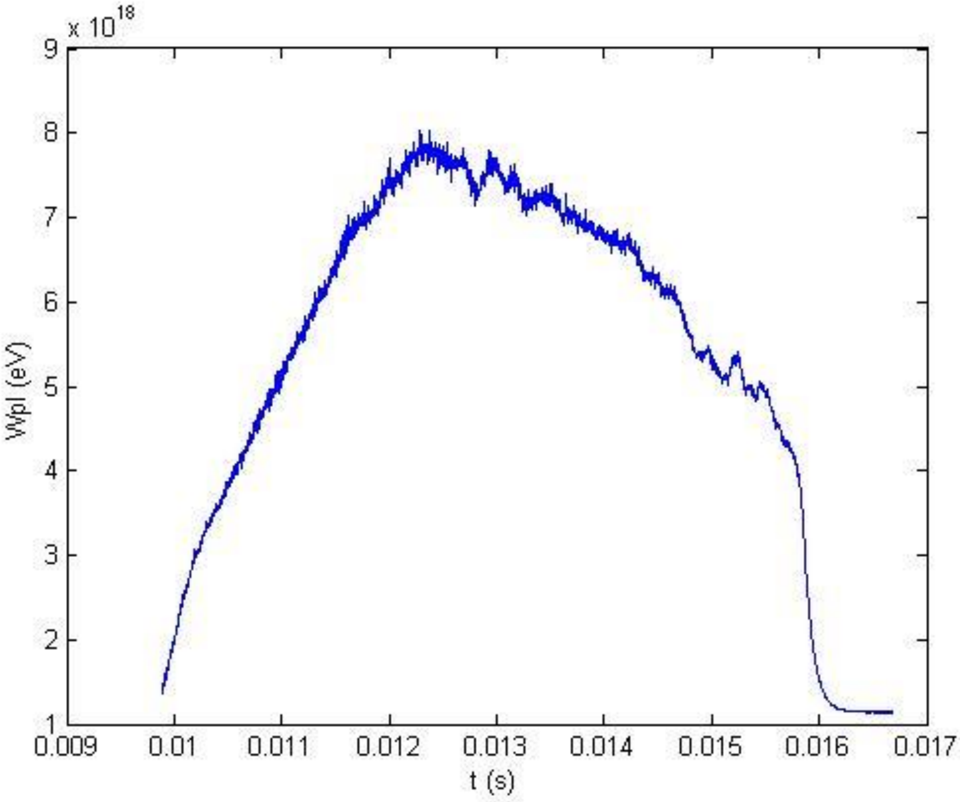


Figure 10.) Highest plasma energy in shot 17188

As shown in the figures, the monitored parameters follow the phases of the plasma breakdown and their magnitudes are between the expected intervall, proving the used claculation methods right.

q=2 disruption

At the end of our session we attempted to reach a plasma breakdown with a safety factor of 2. The following are the Hugill diagramms of those shots.

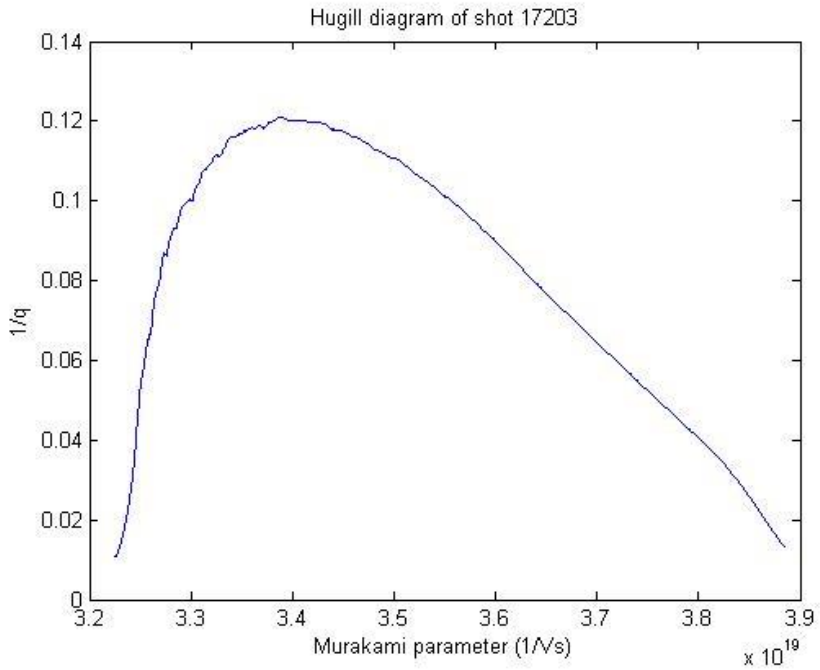


Figure 10.) Hugill diagram of shot 17203

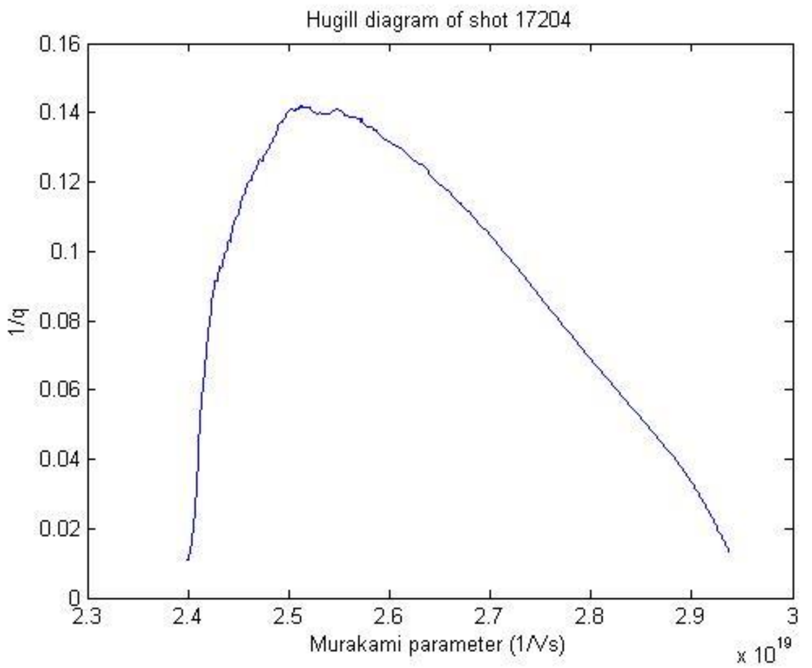


Figure 11.) Hugill diagram of shot 17204

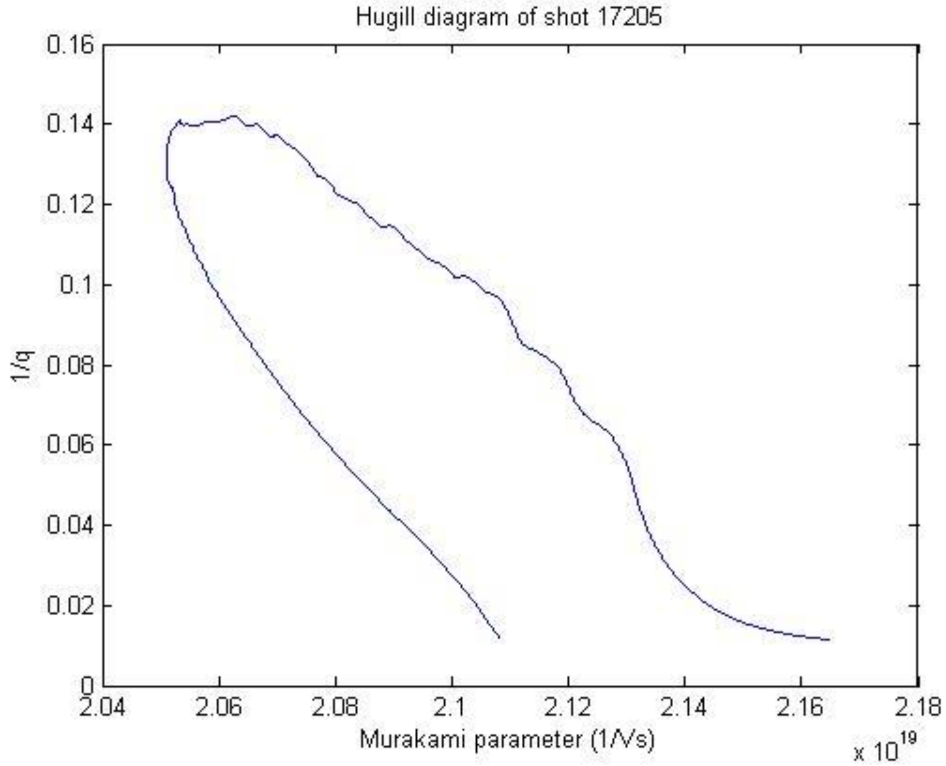


Figure 12.) Hugill diagram of shot 17205

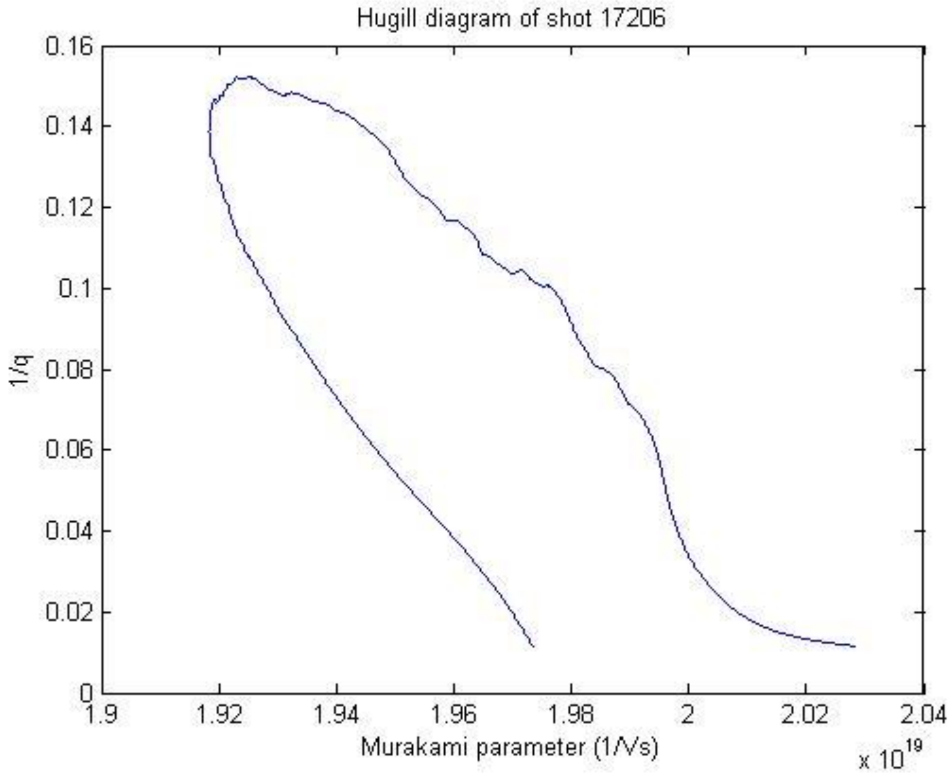


Figure 13.) Hugill diagram of shot 17206

As it can be seen, we could not get near to the q=2 safety factor with the alteration of the gas pressure which explains why we did not experience the discharge disruption.

For verification we investigated some of the previous shots on Hugill-diagram, wether they reached q=2.

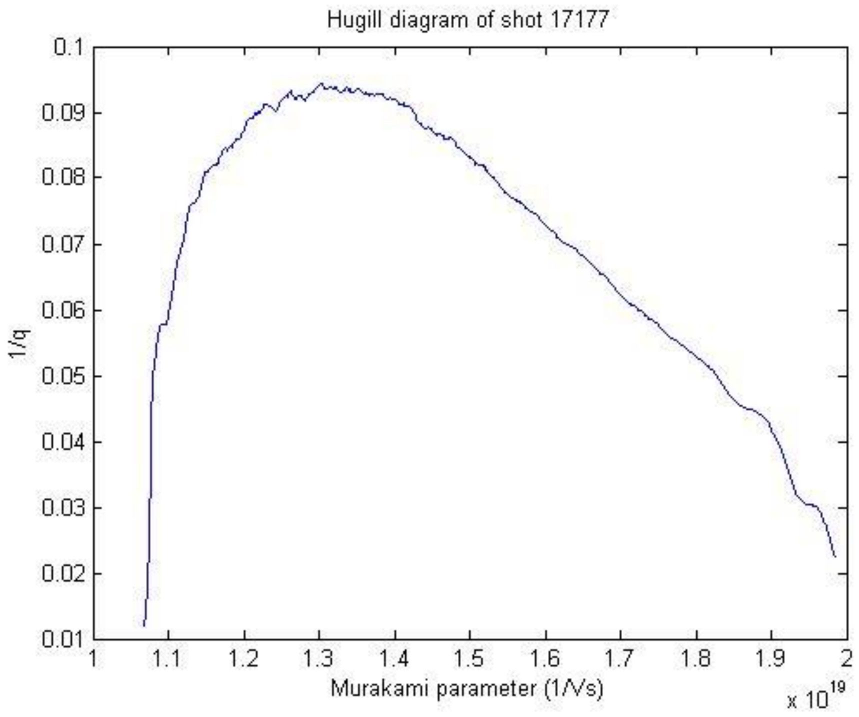


Figure 14.) Hugill diagram of shot 17177

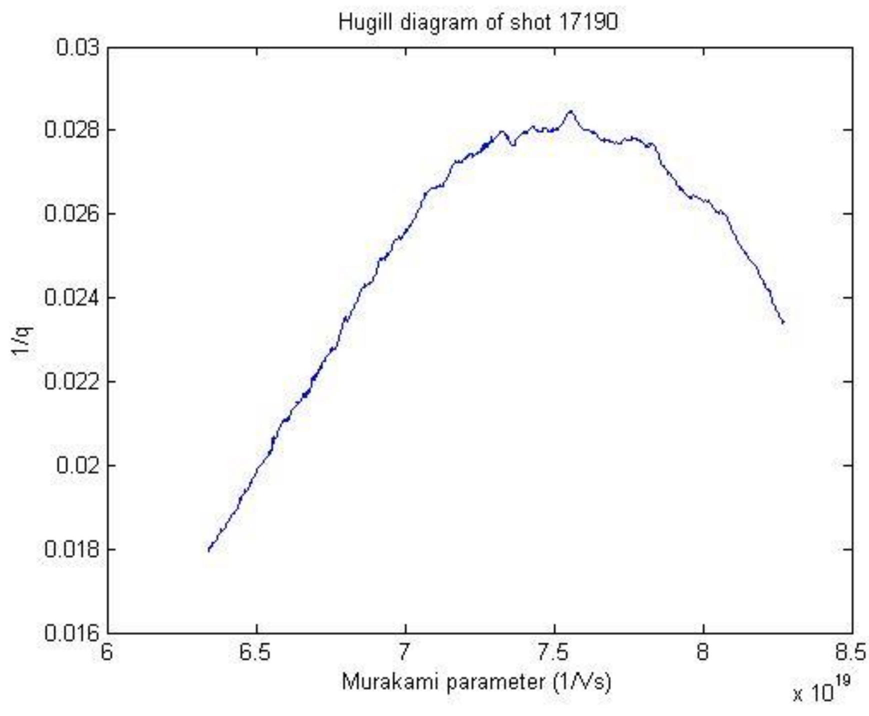


Figure 15.) Hugill diagram of shot 17190

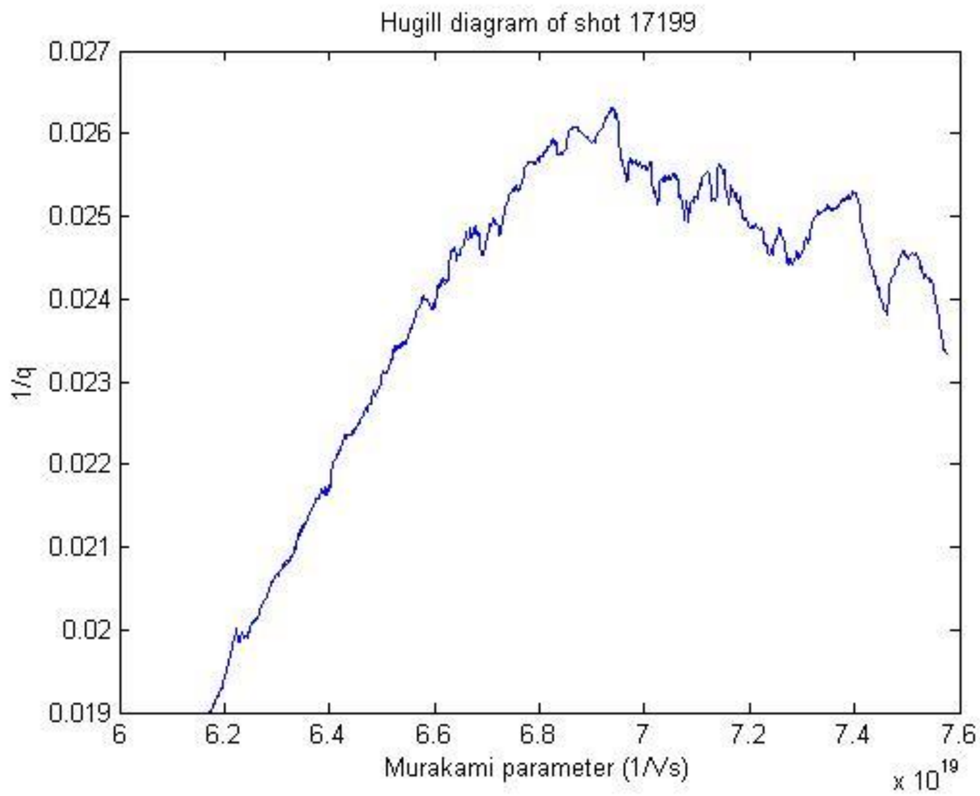


Figure 16.) Hugill diagram of shot 17199

As we expected neither of them nears the q=2 value but the shape of the diagram can be changed drastically by the plasma parameters.

Appendix

Appendix 1, 'master1.m' script for plotting data, and fitting the chamber parameters

```
function []=master1(shot_nr)

[rawdata]=GOLEM_get_data(shot_nr); %running the routine, which gets the raw
data
 GOLEM_plot_rawdata(shot_nr); %plotting the raw datas
 time   = rawdata.timedata.t; %the time variable

% Plot of U_l, computed

U_l_cal=rawdata.timedata.U_l*rawdata.U_loop_calibration; %calibration
figure('Name','Calculated data','NumberTitle','off')
subplot(2,2,1)
plot(time,U_l_cal)
    xlabel('time [s]')
    ylabel('loop voltage [V]')

% Plot of B_t, computed

[signalB] =
GOLEM_offset_correction(rawdata.timedata.dB_t,time,0,rawdata.trigger-
0.0001); %offset correction
intsignalB = GOLEM_integrate(time,signalB); %integration
B_t_cal=intsignalB*rawdata.Bt_calibration; %calibration
subplot(2,2,2)
plot(time,B_t_cal)
    xlabel('time [s]')
    ylabel('Bt [T]')

% Plot of I_tot, computed

[signalI] =
GOLEM_offset_correction(rawdata.timedata.dI_t,time,0,rawdata.trigger-
0.0001); %offset correction
dI_t_cal=signalI*rawdata.Rogowski_calibration; %calibration
intsignalI = GOLEM_integrate(time,dI_t_cal); %integration
[I_t_veg] =
GOLEM_offset_correction(intsignalI,time,rawdata.trigger+0.0001,rawdata.trig
ger+rawdata.time_delay); %secund offset correction
subplot(2,2,3)
plot(time,I_t_veg)
    xlabel('time [s]')
    ylabel('It [A]')

% Plot of Ph

subplot(2,2,4)
plot(time,rawdata.timedata.Photo)
    xlabel('time [s]')
    ylabel('Photodiode  [V]')

% Computation of the seeked parameters

[vtime] =
GOLEM_cut_data(time,time,rawdata.trigger+rawdata.time_delay,time(end));
%cutting of the time variable to suit the datas of interest
```

```
% Cutting the data vectors to the region of interest

[vagottU_l] =
GOLEM_cut_data(U_l_cal,time,rawdata.trigger+rawdata.time_delay,time(end));
[vagottI_t] =
GOLEM_cut_data(I_t_veg,time,rawdata.trigger+rawdata.time_delay,time(end));
[vagottdI_t] =
GOLEM_cut_data(dI_t_cal,time,rawdata.trigger+rawdata.time_delay,time(end));

[ered]=polyfit(vagottdI_t./vagottI_t,vagottU_l./vagottI_t,1); %data fitting
to get the required chamber parameters
L_ch=ered(1)
R_ch=ered(2)
```

Appendix 2, 'master2.m' script for computation of the plasma parameters

```
function []=master2(shot_nr)

close all

k_B=8.6173e-5; %Boltzmann-constant (eV/K)
mu0=4*pi*1e-7; %Vacuum permeability (Vs/Am)

% The basic methods of computation are the same as in function 'master1'

[rawdata]=GOLEM_get_data(shot_nr);

time  = rawdata.timedata.t;

% U_l

U_l_cal=rawdata.timedata.U_l*rawdata.U_loop_calibration;


% B_t

[signalB] =
GOLEM_offset_correction(rawdata.timedata.dB_t,time,0,rawdata.trigger-
0.0001);
intsignalB = GOLEM_integrate(time,signalB);
B_t_cal=intsignalB*rawdata.Bt_calibration;

% I_tot

[signalI] =
GOLEM_offset_correction(rawdata.timedata.dI_t,time,0,rawdata.trigger-
0.0001);
dI_t_cal=signalI*rawdata.Rogowski_calibration;
intsignalI = GOLEM_integrate(time,dI_t_cal);
[I_t_veg] =
GOLEM_offset_correction(intsignalI,time,rawdata.trigger+0.0001,rawdata.trig
ger+rawdata.time_delay);

% Cutting the data vectors to the region of interest
```

```
[vtime] =
GOLEM_cut_data(time,time,rawdata.trigger+rawdata.time_delay,time(end));
[vagottU_l] =
GOLEM_cut_data(U_l_cal,time,rawdata.trigger+rawdata.time_delay,time(end));
[vagottI_t] =
GOLEM_cut_data(I_t_veg,time,rawdata.trigger+rawdata.time_delay,time(end));
[vagottdI_t] =
GOLEM_cut_data(dI_t_cal,time,rawdata.trigger+rawdata.time_delay,time(end));
[vagottB_t] =
GOLEM_cut_data(B_t_cal,time,rawdata.trigger+rawdata.time_delay,time(end));

% Previously determined constants

R_ch=1.04e-2;
L_ch=4.14e-7;

% I_ch, I_p

I_ch = GOLEM_chamber_current(vtime, vagottI_t, vagottU_l, R_ch, L_ch);

I_p=vagottI_t-I_ch;

[dI_p]=GOLEM_diff(I_p,vtime);

% Findig the plasma breakdown

[int]=find(I_p>200);

[vagt] = GOLEM_cut_data(vtime,vtime,vtime(int(1)),vtime(int(end)));
[vagI_p] = GOLEM_cut_data(I_p,vtime,vtime(int(1)),vtime(int(end))); %Plasma
current
[vagU_l] = GOLEM_cut_data(vagottU_l,vtime,vtime(int(1)),vtime(int(end)));
[vagB_t] = GOLEM_cut_data(vagottB_t,vtime,vtime(int(1)),vtime(int(end)));

% Computation of the seeked parameters

maxI_p=max(I_p); %Maximum of the plasma current (A)

t_dc=vagt(end)-vagt(1); %Discharge duration (s)

R_p=vagU_l./vagI_p; %Plasma resistance (ohm)
maxR_p=max(R_p);

P_OH=R_p.*vagI_p.^2; %Ohmic heating (W)
maxP_OH=max(P_OH);

T_e0=(0.4/0.085^2*8*2.5/1544./R_p).^(2./3); %Central electron temperature
(eV)
maxT_e0=max(T_e0);

n_avr=2*rawdata.pressure*1e-3/(k_B*rawdata.T_ch*1.60217657e-19); %Average
electron density (1/m3)

V_p=2*pi^2*0.4*0.085^2; %Plasma volume (m3)
W_pl=V_p*n_avr*k_B*(T_e0*11604.505)/3; %Plasma energy (eV)
maxW_pl=max(W_pl);

[dW_pl]=transpose(GOLEM_diff(W_pl,vagt));
```

```
P_loss=P_OH-(dW_pl*1.60217657e-19); %Loss power (W)
tau_E=(W_pl*1.60217657e-19)./P_loss; %Energy confinement time (s)
maxtau_E=max(tau_E);

recq=0.4*mu0/2/pi/0.085^2.*vagI_p./vagB_t; %Inverse edge safety factor
M=0.4*n_avr./vagB_t; %Murakami parameter
```

Appendix 3, Skype log

[15:16:16] *** Gergő Pokol meghívta NTI Hallgató, Tokamak GOLEM-t a konferenciára ***

[15:16:36] Gergő Pokol: Hi, Vojtech.

[15:16:46] Gergő Pokol: We are getting ready for the measurements.

[15:17:18] Tokamak GOLEM: Hi, best regards from Prague, how are you?

[15:17:43] NTI Hallgató: Hello, we are great, thank you.

[15:18:15] Tokamak GOLEM: Perfect, so the tokamak is ready for your measurement, go ahead

[15:18:59] Tokamak GOLEM: If you have any question, problem, do not hesitate to ask ..

[15:19:19] NTI Hallgató: first we will try a vacuum discharge

[15:19:26] Tokamak GOLEM: OK

[15:25:22] NTI Hallgató: we pushed the button, we started the discharge

[15:26:22] Tokamak GOLEM: Yes, thi is not a vacuum discharge. Congratulations to plasma from Budapest

[15:28:29] NTI Hallgató: we will try again

[15:28:42] Tokamak GOLEM: ok;

[15:33:05] NTI Hallgató: now we will start the third measurement

[15:38:39] Tokamak GOLEM: ok

[15:38:47] NTI Hallgató: we will try to find the breakdown point

[15:41:20] Tokamak GOLEM: ok

[15:58:31] NTI Hallgató: coud you tell us if the electron gun is working?

[15:58:57] Tokamak GOLEM: I think yes, please wait, I will check it

[16:05:43] Tokamak GOLEM: Ca you see IP camera looking into the chamber?

[16:06:15] Tokamak GOLEM: Menu -> IP cameras

[16:06:26] NTI Hallgató: internet connection isn't very good

[16:06:42] NTI Hallgató: we're waiting for it to refresh

[16:07:04] Tokamak GOLEM: So I switch el gun ON now

[16:07:16] NTI Hallgató: thank you

[16:07:35] Tokamak GOLEM: Can you see the light in the chamber?

[16:07:58] Tokamak GOLEM: sorry, Do you ..

[16:08:11] NTI Hallgató: no we cant see

[16:09:49] Tokamak GOLEM: So, the connection should be very poor, it is a pitty. My statement is that the El gun IS working ..

[16:15:02] NTI Hallgató: ok, thanks

[16:18:30] NTI Hallgató: vao, we see the light in the chamber :)

[16:21:04] Tokamak GOLEM: Yes, when you check the el. gun fo preionization then you can see yellow light from the heated filament. And if the connection is OK and you are a bit lucky, than you can see even white flash - this is plasma itself.

[16:23:05] Tokamak GOLEM: Everything OK? According to your expectations?

[16:26:10] NTI Hallgató: yes, i think so

[16:27:20] NTI Hallgató: now we will start letting in H-gas

[16:27:34] Tokamak GOLEM: OK

[16:40:50] NTI Hallgató: do you know what the pressure value is in the last breakdown?

[16:45:40] Tokamak GOLEM: There is a problem, you should repeat last two shots. Let mi check the system ..

[16:45:55] NTI Hallgató: ok

[16:46:08] NTI Hallgató: tell us when we can continue

[16:48:20] Tokamak GOLEM: It seems to me OK, you can continue ..

[16:49:58] NTI Hallgató: ok

[16:52:46] NTI Hallgató: there is a problem, we can't send the parameters on the website, it says that the server is not found

[16:54:05] NTI Hallgató: are you doing the breakdown or we are?

[16:55:33] Tokamak GOLEM: moment

[16:56:49] Tokamak GOLEM: so .. it is working ...

[17:01:54] NTI Hallgató: we think there is something wrong with the pressure measurement

[17:02:35] Tokamak GOLEM: Yes we have a problem with working gas filling. Maybe try to increase step by step, not 3 to 65...

[17:02:41] Tokamak GOLEM: moment, I will check it

[17:03:58] NTI Hallgató: we wanted to go from 65, down by 5 steps, but we will go from 20 upward

[17:04:19] Tokamak GOLEM: it is better, but please moment

[17:04:55] NTI Hallgató: ok, we are waiting for you

[17:07:08] Tokamak GOLEM: Now you can go on, please check the pressure every shot, thank you

[17:07:29] NTI Hallgató: ok

[17:10:20] Tokamak GOLEM: Please, can you make a photo of the classroom with students and send me it? Thank you in advance.

[17:12:44] NTI Hallgató: Gergő took the photos, he will send you

[17:12:58] Tokamak GOLEM: Thanks

[17:20:08] Tokamak GOLEM: The filling system is not very good, when you request 30 and getting 37, try to do it once more again to 30. Try now 30, then 35, then 40, we will see....

[17:34:21] Tokamak GOLEM: Try 35 once more again

[17:34:44] NTI Hallgató: ok

[17:37:41] Tokamak GOLEM: There is probably some SW problem in the gas valve. Sorry.

[17:45:51] NTI Hallgató: this is better, because the measurements are good, we just cant control it very accurately

[18:35:38] Tokamak GOLEM: Can I ask you about your plans? How many discharges do you plan?

[18:36:49] NTI Hallgató: we want about 5 more

[18:53:56] Tokamak GOLEM: So ...?

[18:54:18] NTI Hallgató: we are done

[18:54:25] NTI Hallgató: thank you very mush

[18:54:43] NTI Hallgató: Gergő says he will send you the photos

[18:55:05] Tokamak GOLEM: OK thank you. Hope to receive a good report from today's measurement

[18:55:13] Tokamak GOLEM: Thank you

[18:55:38] NTI Hallgató: and we will send you the report

[18:55:58] Tokamak GOLEM: Best regards to Gergo, we will have a second measurement in two weeks

[18:56:50] Tokamak GOLEM: We will appreciate any feedback, comments, suggestions ..

[18:57:30] NTI Hallgató: ok, thank you, good bye

[18:57:39] Tokamak GOLEM: Good bye