Measurement logbook

Student measurement on the GOLEM tokamak

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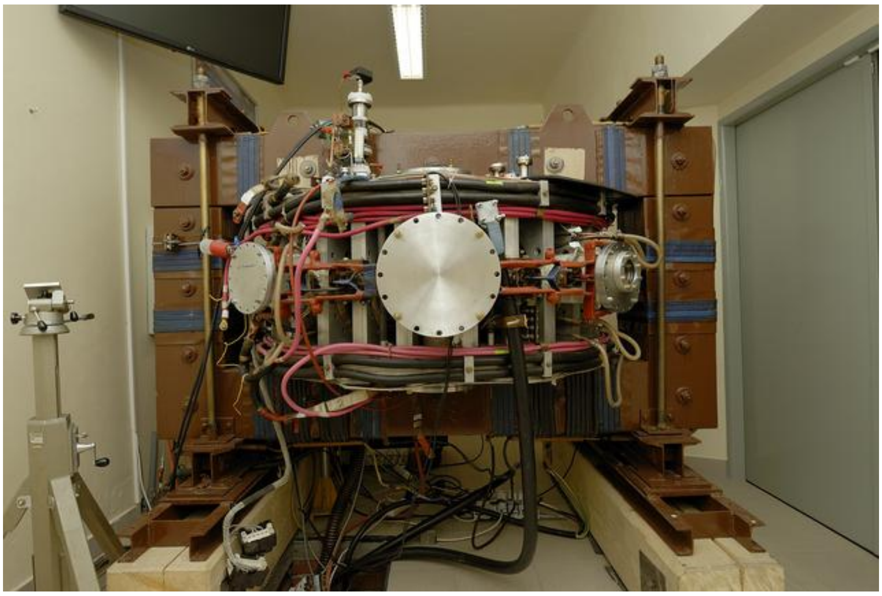
1. Introduction

As the first session of a regular measurement program at the Institute of Nuclear Techniques at the Budapest University of Technology and Economics, a web based remote measurement was performed on the GOLEM tokamak, located at the Czech Technical University in Prague. GOLEM (shown in picture below) is a tokamak with full remote capability, equipped with basic diagnostics for educational purposes. Having dimensions 0.4 m major radius (R_0), 0.1 m minor radius (r_0) and 0.085 m limiter radial position (a), the device is a small size tokamak originally constructed in the Soviet Union as one of the first operational tokamaks in the world.



The goal of the student measurement was the introduction of the remote operation, and to determine the physical parameters required by the measurement instructions. The whole operation was supervised in Prague by Dr. Vojtech Svoboda, real time communication between him and the BME NTI was established via „Skype" at the beginning of the session. The corresponding Skype log can be found in appendix No.1. of this document.

Connection to the GOLEM server was established through „Putty" using the login name and password provided by Dr. Svoboda. The makefile used for tokamak initialization was edited with „Winscp". As introduced in the measurement instruction, four paramteres were required in the makefile to initiate a shot, these are the voltage of the toroidal magnetic field capacitor (U_b), the voltage of the capacitor bank for the ohmic heating (U_e), the time delay between the triggers of the magnetic field and the ohmic heating (T_d) and hydrogen gas pressure (p_{H2}). The makefile, containing all the shot commands of this session can be found in appendix No.2.

During the shots vacuum chamber pressure (p_{ch}) and vacuum chamber temperature (T_{ch}) were measured and uploaded to the GOLEM website. Four other parameters were measured with a sampling rate of 100 kHz. These are the loop voltage (U_l), the total toroidal current (I_{tot}), the toroidal magnetic field (B_t) and the plasma radiation by a photodiode. These time resolved measurements were available on the GOLEM website, a Matlab script was written and used to download the data, the script can be found in appendix No.3.

The B_t and I_{tot} signals had to be integrated and multiplied by a calibration factor, which are in order $C_B = 170$ and $C_I = 5000$. To correct for the DC bias of the direct measurements, the first 450 data points (each shot starts at the 500th data point) had to be averaged and substracted from the measured values (D(t)) before both I_{tot} and B_t integrations:

$$\langle DC \rangle = \frac{1}{450} \sum_{i=0}^{450} D(i)$$

$$I_{tot} = C_I \int_0^t (D(t') - \langle DC \rangle) dt' = C_I \left(\int_0^t D(t^{'}) dt^{'} - \langle DC \rangle t \right)$$

For this purpose and for the offset correction after the integration, a second Matlab script (henceforth simply called the „script") was used, which eventually incorporated all further calculations in connection with the measurement tasks. Our script was well suited for our evaluation, but to increase evaluation speed for possible future measurements, further optimization and automation is advised. See appendix No.4. for the script code.

2. Measurement tasks

2.1. Vacuum chamber parameters

In order to determine the plasma parameters required by the measurement instruction, our first task was to determine the parameters of the vacuum chamber, the resistance (R_{ch}) and the inductance (L_{ch}). During a vacuum shot, no plasma flows in he vacuum vessel and therefor all the current (I_{tot}) measured by the Rogowski-coil flows in the vessel itself. In this case the following circuit equasion is in effect:

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

Just after switching on the toroidal electric field, the I_{tot} is still close to zero so the following approximation can be used:

$$U_l \cong L_{ch} \frac{dI_{tot}}{dt}$$

On the flat top of the curve however, the simplified equation is the following:

$$U_l \cong I_{tot} R_{ch}$$

A total of six vacuum shots were used for this purpose, the two parameters from the above two equations were calculated in the script for every datapoint and plotted against time, the corresponding value of the desired parameter was determined with the help of the data cursor. The following table contains the parameter values for the six shots, the average value is used from now on as the single best estimate for both parameters:

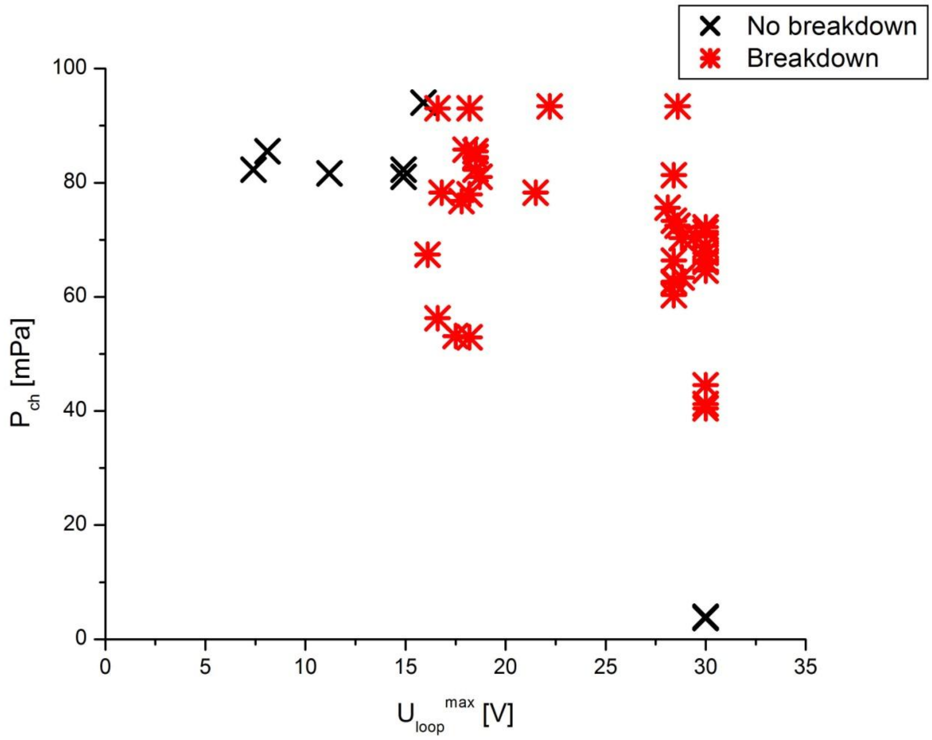
No.	U_b [V]	U_e [V]	T_d [ms]	p_{H2}	L_{ch} [H]	R_{ch} [Ω]
2081	800	500	2000	0	1,81E-06	9,70E-03
2082	600	500	2000	0	2,29E-06	9,80E-03
2083	400	500	2000	0	2,51E-06	1,01E-02
2084	600	300	1000	0	1,85E-06	9,63E-03
2085	600	400	1000	0	1,85E-06	9,63E-03
2086	600	600	1000	0	1,77E-06	9,95E-03
Avg:					**2,01E-06**	**9,80E-03**

2.2. Plasma breakdown

With the vacuum chamber parameters in hand, our next step was to let H_2 gas into the chamber, to create tokamak plasma. As letting the gas into the chamber is not necessarily sufficient to create a plasma breakdown, the determination of the critical discharge parameters for mass ionization is crucial. Originally, shots from 2090 to 2112 were initiated in three loops, to determine how different discharge parameters influenced the occurance of plasma breakdown. Due to lack of time, the proposed 30 discharges for this task were reduced to 23, of which five, No. 2093, 2098, 2100, 2102 and 2109 were unsuccessful because of the problems with the data acquisition system in Prague. Since we could not concentrate the proposed ammount of discharges around the critical line between breakdown and non-breakdown shots, we also used all other remaining shots (2113-2138) for this task during the evaluation. The following table contains the discharge parameters, the chamber pressure and the maximum value of the loop voltage, latter determined with a plot command in the script.

		No.	U_b [V]	U_e [V]	T_d [ms]	p_{H2}	p_{ch} [mPa]	Breakdown	U_l^{max} [V]
Shots to determine plasma breakdown line	**Test shots**	2087	800	500	7500	84	85,50	1	18,0
		2088	800	500	6000	84	84,52	1	18,5
		2089	800	500	4500	84	85,50	1	18,5
	1. loop	2090	800	200	4500	84	85,50	0	8,1
		2091	800	500	4500	84	82,28	1	18,5
		2092	800	800	4500	84	81,34	1	28,4
		2093	Unsuccessful shot						
	2. loop	2094	800	200	4500	84	82,28	0	7,4
		2095	800	300	4500	84	81,65	0	11,2
		2096	800	400	4500	84	81,03	0	14,9
		2097	800	500	4500	84	81,03	1	18,7
	3. loop	2098	Unsuccessful shot						
		2099	800	400	4500	84	82,28	0	14,9
		2100	Unsuccessful shot						
		2101	800	425	4500	78	67,40	1	16,1
		2102	Unsuccessful shot						
		2103	800	425	4500	200	94,03	0	15,9
		2104	800	450	4500	78	56,27	1	16,6
		2105	800	450	4500	84	78,28	1	16,8
		2106	800	450	4500	200	93,04	1	16,6
		2107	800	475	4500	78	53,12	1	17,5
		2108	800	475	4500	84	76,79	1	17,8
		2109	Unsuccessful shot						
		2110	800	500	4500	78	52,92	1	18,2
		2111	800	500	4500	84	77,98	1	18,2
		2112	800	500	4500	200	93,04	1	18,2
Shots to determine main plasma parameters	**1. loop**	2113	800	600	4500	78	78,28	1	21,5
		2114	800	600	4500	200	93,40	1	22,2
		2115	800	800	4500	78	60,30	1	28,4
		2116	800	800	4500	200	93,40	1	28,6
	2. loop	2117	800	800	2000	78	66,37	1	28,4
		2118	800	800	4000	78	75,62	1	28,1
		2119	800	800	6000	78	73,33	1	28,4
		2120	800	800	8000	78	62,42	1	28,4
		2121	800	800	10000	78	63,38	1	28,8
		2122	800	800	10000	78	70,30	1	28,8
		2123	800	800	5000	78	72,49	1	28,6
	3. loop	2124	400	800	4500	78	67,70	1	30,0
		2125	600	800	4500	78	70,57	1	29,5
		2126	800	800	4500	78	62,66	1	28,4
Shots to reach q=2 disruptions	**1. loop**	2127	400	800	4500	78	72,22	1	30,0
		2128	400	800	4500	78	64,61	1	30,0
		2129	400	800	4500	78	66,11	1	30,0
	2. loop	2130	400	800	6000	78	71,39	1	30,0
		2131	400	800	9000	78	68,97	1	30,0
		2132	400	800	12000	78	66,37	1	30,0
	3. loop	2133	400	800	6000	50	3,92	0	30,0
		2134	400	800	9000	50	3,73	0	30,0
		2135	400	800	12000	50	3,70	0	30,0
	4. loop	2136	400	800	6000	73	41,23	1	30,0
		2137	400	800	9000	73	44,52	1	30,0
		2138	400	800	12000	73	40,45	1	30,0

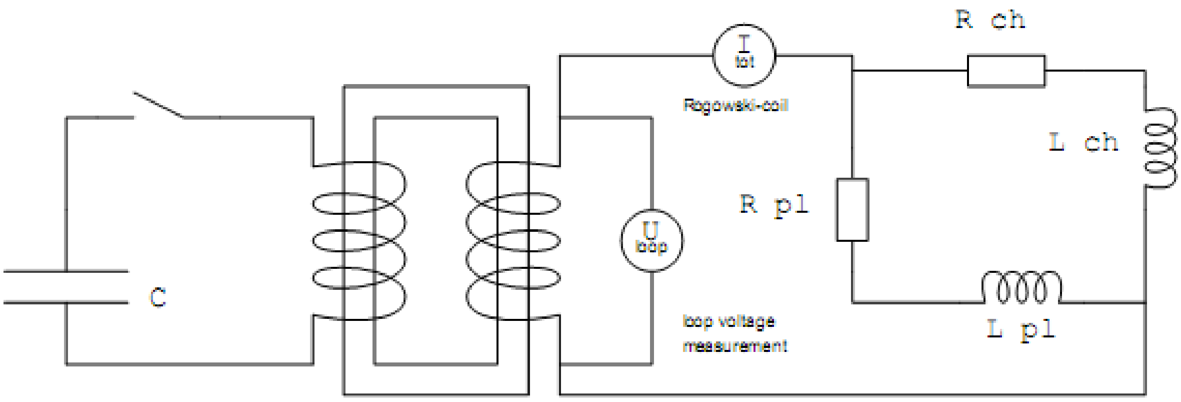
As seen in the following figure, all the above chamber pressure (p_{ch}) values were plotted against the corresponding maximum loop voltage values. Under the given circumstances, our only conclusion is that with the time field capacitor (U_b) set to 800 V and the time delay (T_d) to 4500 ms, a minumum heating capacitor value (U_e) of around 450 V is necessary for plasma breakdown to occure. The gas pressure itself has little influence on plasma breakdown, but an important observation is, that the p_{H2} parameter has a critical value between 50 and 73, where the gas valves do not open, resulting in the lack of gas to be ionized (see shots 2133-2135).



2.3. Estimation of main plasma parameters

Our aim in this task was to investigate the effect of different parameters on the performance of discharge, and to reach discharges with the highest central temperature, plasma energy, or confinement time. Because of our missing experience in plasma physics, and the lack of real-time data evaluation required to see if our discharges produced the desired results, we proceeded with shots 2113 through 2126 with basically changing only two parameters, T_d and p_{H2}. Therefor these 14 shots designated for this task proved unsufficinet, the main plasma parameters were eventually calculated for all our non-vacuum shots during the evaluation. The results are included in the shot summary table in appendix No.5., some example time traces of plasma parameters are shown in appendix No.6.

2.3.1. Plasma current



As seen in the previous figure, a simple electrical model can be applied for the current drive circuit. Both the plasma and the vacuum chamber are modelled by LR circuits, therefor the following basic circuit equasions are in effect:

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

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

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

$$\frac{dI_{tot}(t)}{dt} = \frac{dI_{pl}(t)}{dt} + \frac{dI_{ch}(t)}{dt}$$

Using the initial condition $I_{tot}(0) = I_{ch}(0) = 0$ and the approximation $L_{pl} = 0$, the equasions to be solved are the following:

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

This differential equasion is solved by a simple numerical integration in the script. I_{pl} and R_{pl} are calculated according to previous equasions:

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

$$R_{pl} = \frac{U_l(t)}{I_{pl}(t)}$$

Using the approximation $L_{pl} = L_{ch}$, latter equasion has the following form:

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

I_{pl} and both R_{pl} approximations are calculated in the script, however we have found no significant difference between the two R_{pl} values, therefor only the $L_{pl} = L_{ch}$ approximation was used during futher calculations. Plasma current was calculated and plotted with the script for all shots, the maximum vlaues are shown in the shot summary table in appendix No.5.

2.3.2. PLASMA HEATING POWER

The only heating meachanism of the GOLEM plasma is ohmic heating of the plasma current, which was calculated and plotted in the script, and the maximum value included in the shot summary table for all discharges:

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

2.3.3. CENTRAL ELECTRON TEMPERATURE

The specific resistivity of a fully ionized plasma depends on the electron temperature (T_e) and the effective charge number, which is in our case approximately Z_{eff} = 1,5. For the estimation of this parameter, we use the following equilibrium temeperature profile measured in more detailed measurements:

$$T_e(r,t) = T_{e0}(t) \left(1 - \frac{r^2}{a^2}\right)^2$$

Based on Spitzer's formula, the central electron temperature can be calculated:

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

Although this estimation has large uncertainty, we calculated and plotted it in the script for every shot, and included the maximum values in the shot summary table.

2.3.4. ELECTRON DENSITY

From the state law of ideal gases, an order of magnitude estimation for electron density is possible. We assume that the gas is in themral equilibrium with the chamber wall before the actual shot, and we do not take into account neither that plasma-wall interaction exists, resulting in gas release from the surface, nor that the plasma is not fully ionized. The order of magnitude estimation has the following form:

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

The average electron density has been calculated for all shots, T_{ch} = 298 K was assumed, as the monitored chamber temperature with respect to the room temperature was 0 K for all shots. Reults are included in the shot summary table.

2.3.5. PLASMA ENERGY

Based on the ideal gas law, and the fact, that our magnetic field reduces the degrees of freedom of the particles to two, plasma energy can be calculated:

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

The plasma is torus shaped with major radius of 0,4 m and minor radius of 0,085 m:

$$V = 2R_0 \pi a^2 \pi = 0.05704 m^3$$

Previously calculated central electron temperature values have eV dimension, and were multiplied by 11604,505 for their K equivalent values. The maximum plasma energy values have been calculated for all discharges and included in the shot summary table.

2.3.6. ENERGY CONFINEMENT TIME

During the flat-top, where plasma energy has its maximum, during this time, ohmic heating power equals to to the losses, this enables us to calculate the energy confinement time:

$$\tau_E = \frac{W_{pl}(t_{top})}{P_{OH}(t_{top})}$$

Values have been calculated for all shots, however between our results and the ones provided by Dr. Svoboda on the GOLEM website, there is an approximately two order of magnitude difference (P_{OH} and T_{e0} values are in accordance with the ones on the website, W_{pl} was not calculated by Dr. Svodoba), for which we could not find any explanation. Nevertheless, calculation results are included in the shot summary table.

2.4. q = 2 disruptions

Our last task was to attempt to reach a q = 2 plasma disruption. The edge safety factor (q), which gives the number of toroidal turns required for the magnetic field line at a given magnetic surface to reach its original position poloidally, is approximated on large aspect ratio tokamaks by the following equation:

$$q(r,t) = \frac{rB_t(t)}{R_0 B_p(t)}$$

Using Ampere's law to calculate the poloidal magnetic field at the edge of the plasma (in our case the limiter's poisition), the safety factor is the following:

$$q(a,t) = \frac{2\pi a^2 B_t(t)}{R_0 \mu_0 I_{pl}(t)}$$

Shots 2127 through 2138 were used to reach q = 2 disruptions, unsuccesfully, our smallest claculated value was 3,31 for shot 2128. However q was calculated and plotted with the script for all shots, results are shown in the table on page No.8.

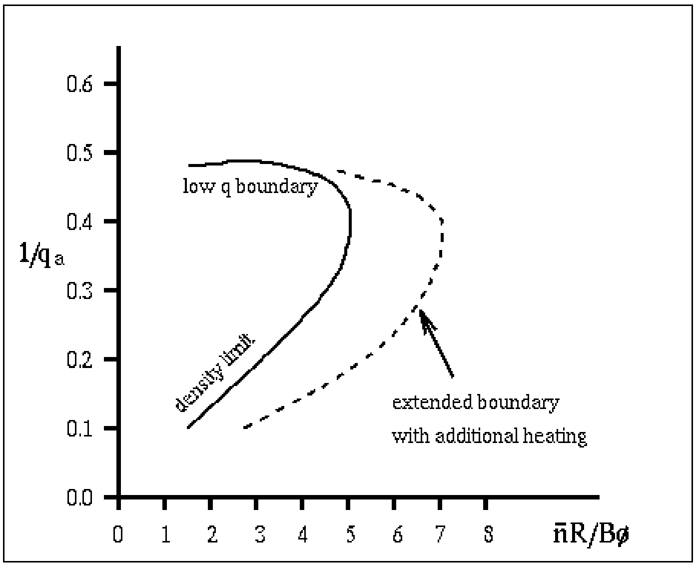
The Hugill diagram is the inverse edge safety factor plotted against the Murakami parameter:

$$M = \frac{n_{avg} R_0}{B_t}$$

It is also possible to make the plot with a Murakami-like parameter, where the calculated average electron density is replaced by the measured chamber pressure:

$$M' = \frac{p_{ch} R_0}{B_t}$$

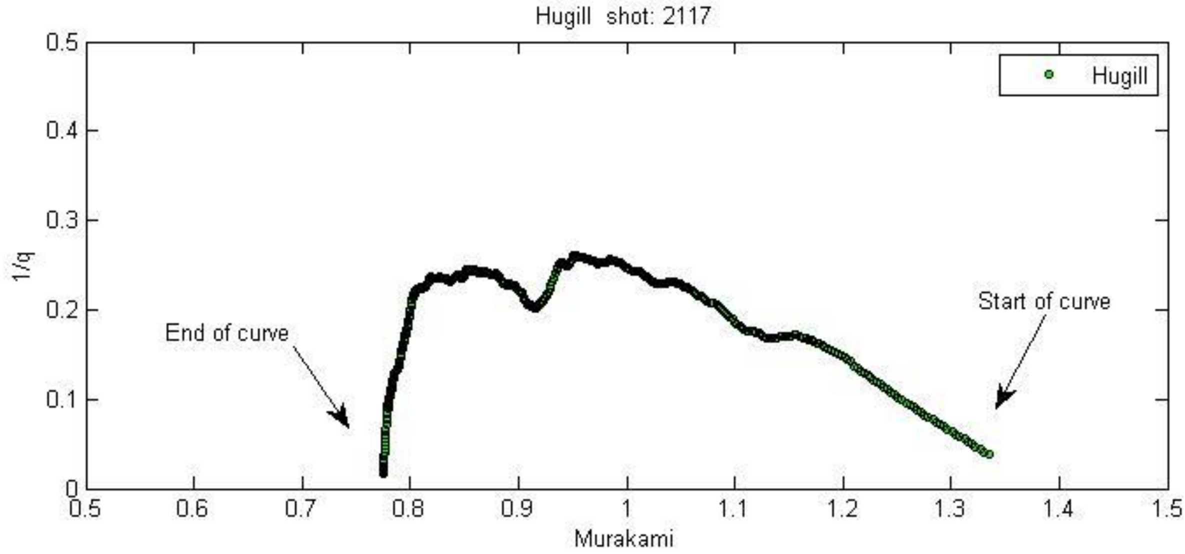
A typical Hugill diagram:



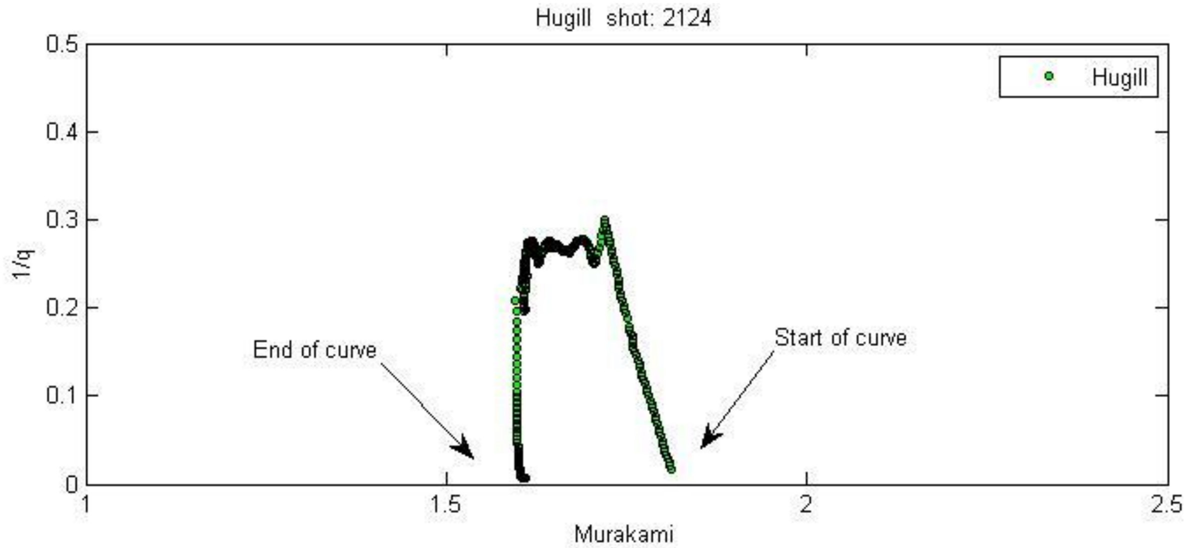
	No.	U_b [V]	U_e [V]	T_d [ms]	p_{H2}	p_{ch} [mPa]	I_{pl}^{max} [A]	q^{max}	$1/q^{max}$
Test shots	2087	800	500	7500	84	85,50	3222	7,20	0,139
	2088	800	500	6000	84	84,52	3305	9,01	0,111
	2089	800	500	4500	84	85,50	3674	8,55	0,117
1. loop	2090	800	200	4500	84	85,50	-	-	
	2091	800	500	4500	84	82,28	3540	8,78	0,114
	2092	800	800	4500	84	81,34	6675	4,71	0,212
	2093	-	-	-	-	-	-	-	-
2. loop	2094	800	200	4500	84	82,28	-	-	-
	2095	800	300	4500	84	81,65	-	-	-
	2096	800	400	4500	84	81,03	-	-	-
	2097	800	500	4500	84	81,03	4277	7,45	0,134
3. loop	2098	-	-	-	-	-	-	-	-
	2099	800	400	4500	84	82,28	-	-	-
	2100	-	-	-	-	-	-	-	-
	2101	800	425	4500	78	67,40	3011	10,37	0,096
	2102	-	-	-	-	-	-	-	-
	2103	800	425	4500	200	94,03	-	-	-
	2104	800	450	4500	78	56,27	3480	9,04	0,111
	2105	800	450	4500	84	78,28	3030	10,45	0,096
	2106	800	450	4500	200	93,04	1589	18,93	0,053
	2107	800	475	4500	78	53,12	4091	7,64	0,131
	2108	800	475	4500	84	76,79	3789	8,30	0,120
	2109	-	-	-	-	-	-	-	-
	2110	800	500	4500	78	52,92	4475	7,18	0,139
	2111	800	500	4500	84	77,98	3556	8,92	0,112
	2112	800	500	4500	200	93,04	3773	8,50	0,118
1. loop	2113	800	600	4500	78	78,28	4574	6,87	0,146
	2114	800	600	4500	200	93,40	4616	6,81	0,147
	2115	800	800	4500	78	60,30	7269	4,25	0,235
	2116	800	800	4500	200	93,40	7512	4,20	0,238
2. loop	2117	800	800	2000	78	66,37	6941	3,83	0,261
	2118	800	800	4000	78	75,62	7008	4,58	0,218
	2119	800	800	6000	78	73,33	7797	3,78	0,265
	2120	800	800	8000	78	62,42	6678	3,84	0,261
	2121	800	800	10000	78	63,38	3833	4,51	0,222
	2122	800	800	10000	78	70,30	4929	4,08	0,245
	2123	800	800	5000	78	72,49	7521	4,08	0,245
3. loop	2124	400	800	4500	78	67,70	4225	3,35	0,299
	2125	600	800	4500	78	70,57	5978	3,96	0,252
	2126	800	800	4500	78	62,66	8323	3,72	0,269
1. loop	2127	400	800	4500	78	72,22	4302	3,51	0,285
	2128	400	800	4500	78	64,61	4418	3,31	0,302
	2129	400	800	4500	78	66,11	3960	3,72	0,269
2. loop	2130	400	800	6000	78	71,39	4537	3,41	0,294
	2131	400	800	9000	78	68,97	3876	3,67	0,272
	2132	400	800	12000	78	66,37	2337	3,38	0,296
3. loop	2133	400	800	6000	50	3,92	-	-	-
	2134	400	800	9000	50	3,73	-	-	-
	2135	400	800	12000	50	3,70	-	-	-
4. loop	2136	400	800	6000	73	41,23	3978	3,91	0,256
	2137	400	800	9000	73	44,52	3251	4,29	0,233
	2138	400	800	12000	73	40,45	2234	3,60	0,278

We attempted to plot the Hugill diagram during some plasma discharges with the Murakami-like parameter, with little result. In order to attain realistic figures, manual change of plotting parameters was required (see script). Our results for some of the shots are shown below:

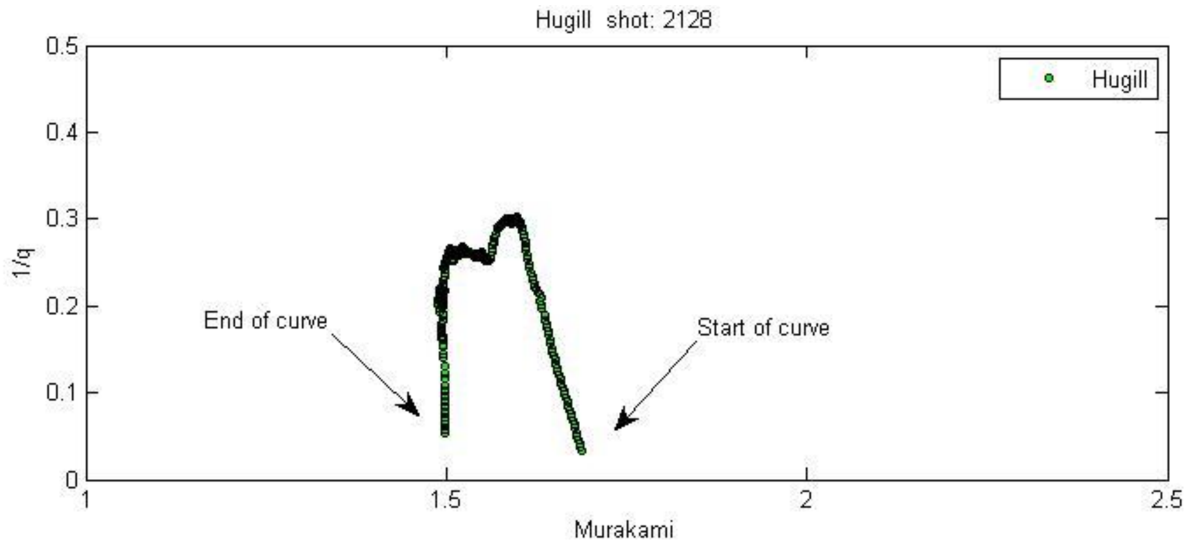
Shot 2117:



Shot 2124:

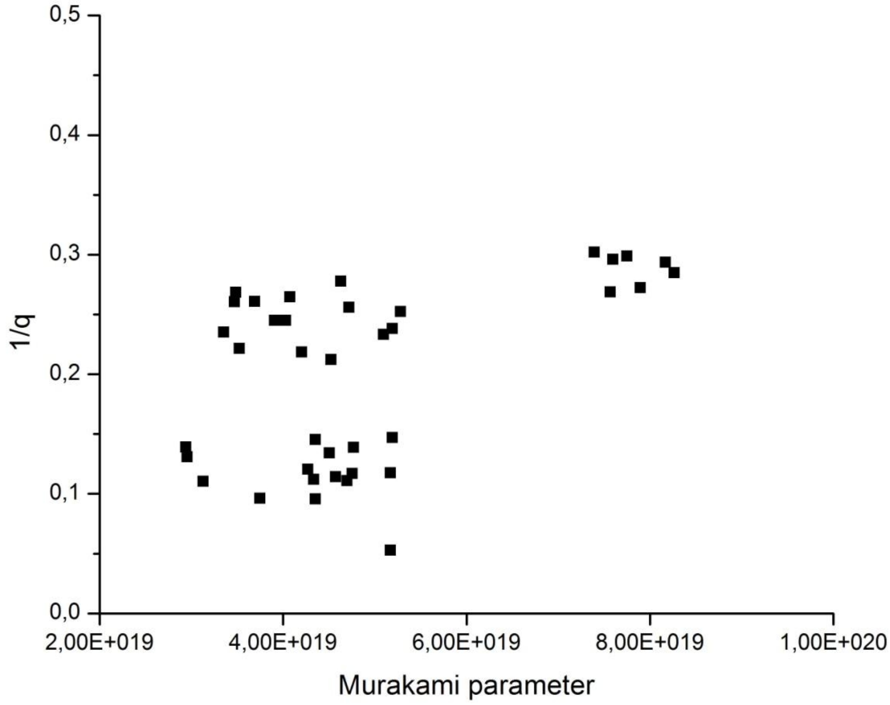


Shot 2128:

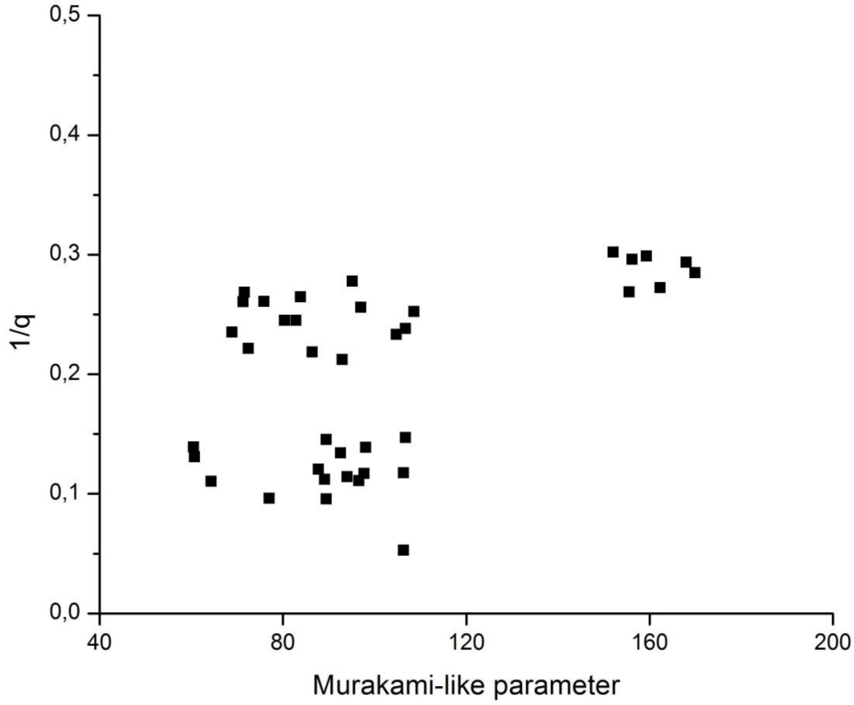


Furthermore we calculated the values of the Murakami and Murakami-like parameteres for all shots, to demonstrate that none of them reach the region above 1/q = 0,5:

With Murakami parameter:

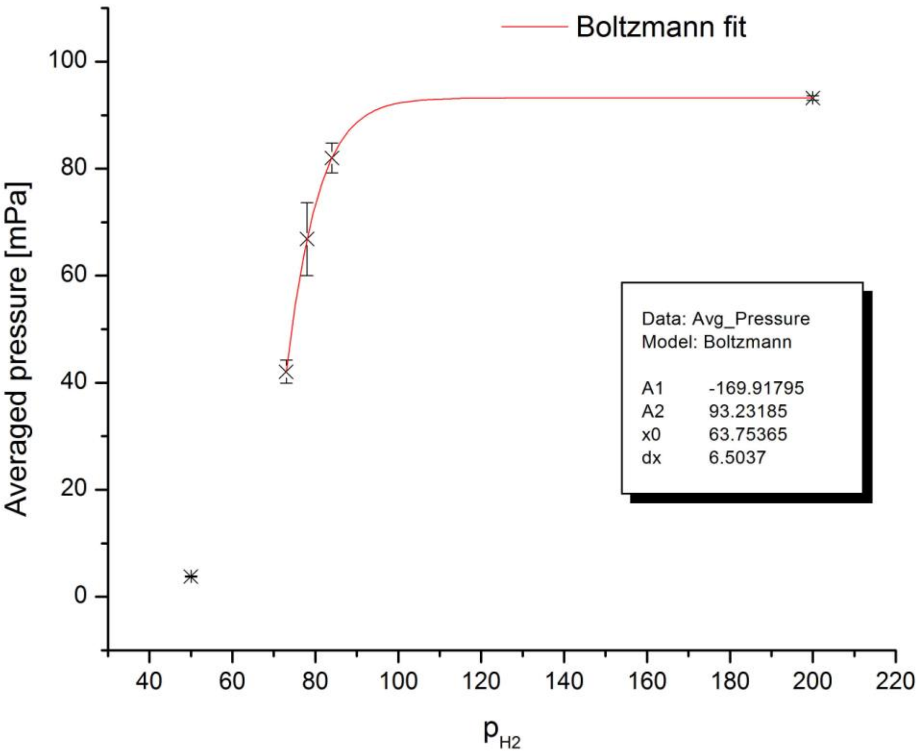


With Murakami-like parameter:



2.5. CHAMBER PRESSURE CALIBRATION

During the measurement session, we encountered the problem of not knowing the anticipated chamber pressure for a specific p_{H2} initial parameter. In order to speed up future measurements, it is advised to include a pressure calibration curve in the measurement instructions. For all our used initial parameters (50, 73, 78, 84, 200), we averaged the corresponding chamber pressure values, and plotted the results:



Value 50 is too low, no gas was released into the chamber, and value 200 is too far away from other data point to be evaluated properly, measurements with a wider range of pressure initial parameter are required for an accurate calibration. On the last four points however, we attempted to fit the following Boltzmann function:

$$p_{ch} = \frac{A_1 - A_2}{1 + e^{(p_{H2} - x_0)/dx}} + A_2$$

It might be useful to use this function as basis for future measurements, the fitted parameter values are:

A_1 = -169,92 A_2 = 93,23 x_0 = 63,75 d_x = 6,50

3. Appendix

3.1. Appendix No.1.: Skypelog

[9:27:53] *** Réfy Dániel meghívta NTI Hallgató-t a konferenciára ***
[9:28:26] Réfy Dániel: hallo nti student!?
[9:28:45] NTI Hallgató: present
[9:28:50] gergo_pokol: OK, let's go, please login to buon.fjfi.cvut.cz via putty with name golem and paswd: janwerich
[9:28:58] gergo_pokol: After login, please make a command: cd operation, there you find your makefile
[9:28:58] NTI Hallgató: test
[9:32:35] NTI Hallgató: We have just logged into the server.
[9:33:05] svobovoj: OK
[9:35:14] NTI Hallgató: we would like to make our makefile.
[9:35:30] NTI Hallgató: Shall we rewrite the old one?
[9:35:43] svobovoj: Yes, you can
[9:36:25] svobovoj: I suggest to start with single shots (vacuum, then plasma), then loops ..
[9:37:44] gergo_pokol: would you like to confirm the makefile before the execution?
[9:37:56] svobovoj: Yes, please
[9:42:58] gergo_pokol: MATLAB download srcipt to be found here: http://mtws01.rmki.kfki.hu/~pokol/prog/
[9:44:51] NTI Hallgató: Can you tell us what does it means: DynPlPosCtrl=0 X11=1 ?
[9:45:47] NTI Hallgató: We editted the makefile, check it please.
[9:46:54] svobovoj: DynPlPosCtrl is abr. for Dynamic Plasma Position Control, which is under installation now, but, for today, not working .. It is a switch ON/OFF, X11 is a flag, if you have a X-server, then you can have graphs and charging logs in a more convenient form
[9:48:31] svobovoj: nti_vacuuum is OK, maybe you can use $(COMMENT) to log brief notes about ongoing shot
[9:48:47] svobovoj: nti_vacuum you can "make"
[9:49:11] NTI Hallgató: We changed the last parameter's value to 0.
[9:50:51] svobovoj: OK, it is switched off either from my side
[9:51:04] NTI Hallgató: we are proceeding with the first shot
[9:51:11] svobovoj: OK
[9:51:47] svobovoj: Pleas forgive some error messages aftr the shot ..
[9:52:07] svobovoj: It is charging ..
[9:52:44] svobovoj: Do you have IP camera on? And speakers? Audio and video is ON.
[9:54:03] svobovoj: OK
[9:54:11] gergo_pokol: I could not yet set up the camera. Am I right that I will need Quicktime for that?
[9:54:52] svobovoj: You need Internet explorer with some plugin, maybe quick time and ActiveX on ..
[9:55:17] svobovoj: In a windows, it is a automatic installation ..
[10:02:44] NTI Hallgató: We would like know the new name of Td_actual. Thanks.
[10:03:35] svobovoj: I am not sure, what you mean..
[10:05:07] svobovoj: ...Td is time delay between the magnetic field trigger and electric field trigger
[10:05:27] gergo_pokol: previosly we could download the value of time delay from operation/shots/shotnumber/Td_aktual
[10:05:58] gergo_pokol: it does not wotk for current shots
[10:05:59] svobovoj: Aha, you are right. Now /sorry/ it shoul be Te_actual ..
[10:07:19] svobovoj: I had to rename it, because of new acquired time delays .. break down voltage delay and plasma control position delay, triggers, which are now under construction ..
[10:09:01] svobovoj: Sorry, Te_aktual
[10:09:19] svobovoj: english/czech problem
[10:10:04] NTI Hallgató: We make the second shot.
[10:10:13] svobovoj: OK
[10:11:10] *** Réfy Dániel meghívta Buday Csaba-t a konferenciára ***
[10:12:25] svobovoj: Best regards from Prague
[10:13:10] Buday Csaba: Thank you
[10:14:38] NTI Hallgató: We wolud like to 4 more vacuum shots. Can we start them?
[10:15:45] svobovoj: OK
[10:20:44] Réfy Dániel: we see and hear you guys! :)
[10:23:25] svobovoj: That is great ..
[10:25:01] svobovoj: You can ask me to mix two channels: from tokamak and from infrastructure room with the rotary pump and condensators. It is possible to change relative volume of these two channels ..
[10:26:28] Réfy Dániel: a bit less from pumps would be nice!
[10:26:58] NTI Hallgató: We would like to proceed with a plasma shot.
[10:27:33] svobovoj: pumps have been decreased.
[10:27:58] Réfy Dániel: better!
[10:28:28] svobovoj: make: nti_plasma1 should be H2filling=1
[10:29:20] NTI Hallgató: sorry, we have already corrected it.
[10:29:53] svobovoj: OK, let's go
[10:33:07] svobovoj: Congratulations! Plasma from Budapest, again!
[10:33:15] svobovoj: Please, can we have a small /5 min/ break?

[10:35:46] NTI Hallgató: ok
[10:46:39] svobovoj: I am back again
[10:47:44] NTI Hallgató: can we make the second shot?
[10:48:24] svobovoj: OK, go on
[10:58:09] NTI Hallgató: can we make another plasma shot before the loop?
[10:58:26] svobovoj: yes
[10:59:40] svobovoj: My students have a question, if it is possible for a few shots unplug the photodiode. They want to make a photo of the plasma discharge.
[11:00:24] NTI Hallgató: sure
[11:00:45] NTI Hallgató: can you send us the photo?:)
[11:02:52] svobovoj: Yes, of course
[11:03:52] svobovoj: Photodiode unplugged...
[11:05:23] svobovoj: I have a question, how long you plan this today's session ?
[11:06:37] gergo_pokol: Ithink, this is a question for me...
[11:09:03] NTI Hallgató: we would like to retry the last shot, because we can't see the data
[11:09:27] gergo_pokol: We are still at task 3.2, but things should speed up a little bit with loops. 12:30 might be realistic.
[11:10:54] svobovoj: Last shot .. it is my problem, unfortunately, i have to make some after shot matter manualy. Last shot is OK now
[11:11:16] svobovoj: http://golem.fjfi.cvut.cz/operation/currentshot/ is working properly
[11:11:48] svobovoj: 12:30 is OK with me
[11:12:30] NTI Hallgató: thank you, we have the data, please check the makefile, so we may proceed with the first loop
[11:14:13] svobovoj: OK, go on
[11:18:55] svobovoj: what are you waiting for?
[11:19:35] NTI Hallgató: it doesn't work, because we have a sintax error.
[11:20:25] NTI Hallgató: do you any suggestion for us?
[11:20:37] NTI Hallgató: do you have
[11:20:41] svobovoj: moment
[11:22:22] svobovoj: it looks fine
[11:22:45] NTI Hallgató: that's our problem too
[11:24:40] svobovoj: try it now
[11:25:12] svobovoj: do\   changed to do \
[11:25:47] NTI Hallgató: thank you, we really didn't know that one...
[11:35:05] NTI Hallgató: we'd proceed with another loop...
[11:36:16] svobovoj: OK
[11:38:10] svobovoj: moment
[11:39:10] svobovoj: now it is OK, ' changed to `
[11:51:42] NTI Hallgató: we would like to do loop nr.3
[11:55:27] svobovoj: What do you intend to do with pH2 40,70,100?
[11:55:51] svobovoj: Is it 40,70,100 mPa?
[11:56:36] NTI Hallgató: to see if plasma breakdown depends on it.
[11:57:00] NTI Hallgató: and yes it's mPa
[11:59:30] svobovoj: If it is mPa, then, please, use 78,84,200, my pH2 units are something like current to the valve. So 40, 80, 100 mPa will be with pH2=78,84,200 approximately. Sorry for the inconvenient
[12:00:23] NTI Hallgató: we are ready
[12:00:28] svobovoj: go on
[12:00:28] NTI Hallgató: thanks
[12:00:59] gergo_pokol: what is the range for parameter pH2?
[12:11:41] svobovoj: Unfortunately, from time to time there is a problem with the DAS
[12:12:54] NTI Hallgató: funny question: what does DAS stand for?
[12:13:26] svobovoj: Sorry, Data Acquisition System
[12:14:30] svobovoj: e.g. 2102 was a plasma, we have made a photo of it ..but DAS failed
[12:19:16] svobovoj: Gergo and Daniel have a photo of 2097 discharge in a mail.
[12:22:27] NTI Hallgató: thank you, nice picture to put in the logbook
[12:22:43] svobovoj: you are welcome
[12:23:29] NTI Hallgató: do you know why it's blue colored?
[12:24:51] svobovoj: It is a Balmer serie of the hydrogen - visible part
[12:25:43 | Módosítva 12:26:04] svobovoj: Here you have a glow discharge from the GOLEM http://golem.fjfi.cvut.cz/?p=glowdisch
[12:35:32] gergo_pokol: We are proggressing slower than expected. We have 2 more tasks to go. How much time do we have?
[12:36:56] svobovoj: Let's try one more hour .. and then we'll see
[12:37:39] gergo_pokol: ok, thanks!
[12:37:50] NTI Hallgató: than we'd proceed with the next task with a new loop
[12:38:25] svobovoj: OK, go on
[12:54:42] NTI Hallgató: we'd start the next loop
[12:56:14] svobovoj: OK, go on
[13:11:47] NTI Hallgató: we'll start the next loop
[13:12:26] svobovoj: OK
[13:17:45] NTI Hallgató: one more loop for this task...
[13:19:49] svobovoj: OK
[13:27:54] NTI Hallgató: ok, last task! we'll do the next loop
[13:28:16] svobovoj: OK
[13:36:14] NTI Hallgató: we will do the next loop
[13:37:34] svobovoj: Which one? loop8 is acording the makefile tha last one
[13:38:29] NTI Hallgató: sorry, we mistyped and the "for" cycle didn't went down, beacause Td=4500 was still in the last line...
[13:38:38] NTI Hallgató: but loop8 is now correct

[13:39:49] svobovoj: aha, OK, go on
[13:50:05] NTI Hallgató: we'll try another loop with lower pressure.
[13:50:30] svobovoj: OK
[13:57:07] NTI Hallgató: we'd make the next loop with another pressure value
[13:58:35] svobovoj: What kind of pressure you want to reach? You know, after lunch I have some duty.
[13:58:48] NTI Hallgató: 40 mPa
[13:59:29] NTI Hallgató: hopefully this will be the last loop
[13:59:45] gergo_pokol: This will be the last loop.
[14:00:17] NTI Hallgató: can you give us the correct pH2 parameter value for 40 mPa?
[14:00:24] svobovoj: Moment, i 'll try to guess the value
[14:00:30] gergo_pokol: I didn't have breakfast, yet...
[14:03:29] svobovoj: Try 73
[14:03:57] NTI Hallgató: ok
[14:04:15] svobovoj: ok, go on
[14:11:01] gergo_pokol: We are finished.
[14:11:05] gergo_pokol: Thank you!
[14:11:16] NTI Hallgató: Thank you, for the cooperation!
[14:11:24] svobovoj: OK, you are welcome, please notice that we appreciate your comments (http://golem.fjfi.cvut.cz/hodnoceni.html) and welcome the postcard
[14:11:33] gergo_pokol: Logbook is due in 2 weeks.
[14:11:52] gergo_pokol: bye!
[14:11:53] svobovoj: Perfect, Good bye
[14:12:02] NTI Hallgató: Good bye!
[14:12:24] buday_csaba: Good bye!

3.2. Appendix No.2.: Makefile

```
SHOT=make -iBs -C velin shot
COMMENT=make -iBs -C velin wwwcomment COMMENT
LOOPCOMMENT=make -iBs -C velin loopcomment COMMENT
LOOPEND=make -iBs -C velin loopend

aktual:
$(COMMENT)="System check (plasma test)"
$(SHOT) Ub=800 Ue=500 Td=2000  pH2=84 H2filling=1 DynPlPosCtrl=0 X11=1;

archiv:
$(COMMENT)="System check (vacuum test)"
$(SHOT) Ub=400 Ue=400 Td=2000  pH2=84 H2filling=0 DynPlPosCtrl=0 X11=1;

vacuum_test:
$(COMMENT)="System check (vacuum test)"
$(SHOT) Ub=800 Ue=500 Td=2000  pH2=84 H2filling=0 DynPlPosCtrl=0 X11=1;

plasma_test:
$(COMMENT)="System check (plasma test)"
$(SHOT) Ub=800 Ue=500 Td=2000  pH2=84 H2filling=1 DynPlPosCtrl=0 X11=1;

nti_vacuum1:
$(SHOT) Ub=800 Ue=500 Td=2000  pH2=84 H2filling=0 DynPlPosCtrl=0 X11=0;

nti_vacuum2:
$(SHOT) Ub=600 Ue=500 Td=2000  pH2=84 H2filling=0 DynPlPosCtrl=0 X11=0;

nti_vacuum3:
$(SHOT) Ub=400 Ue=500 Td=2000  pH2=84 H2filling=0 DynPlPosCtrl=0 X11=0;

nti_vacuum4:
$(SHOT) Ub=600 Ue=300 Td=1000  pH2=84 H2filling=0 DynPlPosCtrl=0 X11=0;
```

```
nti_vacuum5:
$(SHOT) Ub=600 Ue=400 Td=1000  pH2=84 H2filling=0 DynPlPosCtrl=0 X11=0;

nti_vacuum6:
$(SHOT) Ub=600 Ue=600 Td=1000  pH2=84 H2filling=0 DynPlPosCtrl=0 X11=0;

nti_plasma1:
$(SHOT) Ub=800 Ue=500 Td=7500  pH2=84 H2filling=1 DynPlPosCtrl=0 X11=0;

nti_plasma2:
$(SHOT) Ub=800 Ue=500 Td=6000  pH2=84 H2filling=1 DynPlPosCtrl=0 X11=0;

nti_plasma3:
$(SHOT) Ub=800 Ue=500 Td=4500  pH2=84 H2filling=1 DynPlPosCtrl=0 X11=0;

nti_loop1:
for Ue in 200 500 800; do \
echo $$Ue;\
make -C velin -iBs shot Ue=$$Ue Ub=800 Td=4500 pH2=84 H2filling=1;\
done;\

nti_loop2:
for Ue in `seq 200 100 500`; do \
echo $$Ue;\
make -C velin -iBs shot Ue=$$Ue Ub=800 Td=4500 pH2=84 H2filling=1;\
done;\

nti_loop3:
for Ue in `seq 400 25 500`; do \
echo $$Ue;\
for pH2 in 78 84 200; do \
make -C velin -iBs shot Ue=$$Ue Ub=800 Td=4500 pH2=$$pH2 H2filling=1;\
done;\
done;\

nti_loop4:
for Ue in 600 800; do \
echo $$Ue;\
for pH2 in 78 200; do \
make -C velin -iBs shot Ue=$$Ue Ub=800 Td=4500 pH2=$$pH2 H2filling=1;\
done;\
done;\

nti_loop5:
for Td in `seq 2000 2000 10000`; do \
echo $$Ue;\
make -C velin -iBs shot Ue=800 Ub=800 Td=$$Td pH2=78 H2filling=1;\
done;\

nti_loop6:
for Td in 10000 5000; do \
echo $$Ue;\
make -C velin -iBs shot Ue=800 Ub=800 Td=$$Td pH2=78 H2filling=1;\
done;\
```

```
nti_loop7:
for Ub in `seq 400 200 800`; do \
echo $$Ub;\
make -C velin -iBs shot Ue=800 Ub=$$Ub Td=4500 pH2=78 H2filling=1;\
done;\

nti_loop8bad:
for Td in `seq 6000 3000 12000`; do \
echo $$Td;\
make -C velin -iBs shot Ue=800 Ub=400 Td=4500 pH2=78 H2filling=1;\
done;\

nti_loop8:
for Td in `seq 6000 3000 12000`; do \
echo $$Td;\
make -C velin -iBs shot Ue=800 Ub=400 Td=$$Td pH2=78 H2filling=1;\
done;\

nti_loop9:
for Td in `seq 6000 3000 12000`; do \
echo $$Td;\
make -C velin -iBs shot Ue=800 Ub=400 Td=$$Td pH2=50 H2filling=1;\
done;\

nti_loop10:
for Td in `seq 6000 3000 12000`; do \
echo $$Td;\
make -C velin -iBs shot Ue=800 Ub=400 Td=$$Td pH2=73 H2filling=1;\
done;\
```

Appendix No.3.: Matlab script to download data

```
function [rawdata]=GOLEM_get_data(shot_nr)
% Purpose: Download, save and return GOLEM raw diagnostic data for a given shot
% Input: shot_nr - Shot number in numerical format
% Output: data - returned structure containing raw diagnostic data
% File output: shot_nr.txt file written to the ./shot_data/ directory
% Manual inputs
    room_temp = 300; % [K] room temperature at the tokamak
    samplerate = 1e5; % [Hz] sampling rate of the USB scope
% Compose URL-s to download
    shot_nr_str=int2str(shot_nr);
    addr_prefix='http://golem.fjfi.cvut.cz/operation/shots/';
    addr_scope_postfix='/basicdiagn/usbscopes';
    addr_vacuum_postfix='/Aktual_PfeifferMerkaVakua';
    addr_delay_postfix='/Te_aktual';
    addr_temp_postfix='/Aktual_TermoclanekNaKomore';
    addr_scope=strcat(addr_prefix,shot_nr_str,addr_scope_postfix);
    addr_vacuum=strcat(addr_prefix,shot_nr_str,addr_vacuum_postfix);
    addr_delay=strcat(addr_prefix,shot_nr_str,addr_delay_postfix);
    addr_temp=strcat(addr_prefix,shot_nr_str,addr_temp_postfix);
% Download data
    data_unformatted=urlread(addr_scope); % [V]
    pressure_unformatted=urlread(addr_vacuum); % [mPa]
    time_delay_unformatted=urlread(addr_delay); % [us]
    T_ch_unformatted=urlread(addr_temp); % [K] relative to room temperature
% Write raw data vector to file
    mkdir('shot_data')
    shot_file_name=strcat('shot_data/',shot_nr_str,'.txt');
    shot_file=fopen(shot_file_name,'w');
    fwrite(shot_file,data_unformatted,'char');
    fclose(shot_file);
% Read raw data vector file - check success of write
    timedata=load(shot_file_name,'-ascii');
% Build structure containing the raw data
    rawdata.nr=shot_nr;
    rawdata.pressure=eval(pressure_unformatted); % [mPa]
    rawdata.time_delay=eval(time_delay_unformatted)/1e6; % [s]
    rawdata.T_ch=eval(T_ch_unformatted)+room_temp; % [K]
    rawdata.samplerate=samplerate; % [Hz]
    rawdata.N=size(timedata,1); % length of data vector
    rawdata.timedata.t=linspace(0,rawdata.N*1/rawdata.samplerate,rawdata.N).'; % [s]
time axis
    rawdata.timedata.U_l=timedata(:,1); % [V]
    rawdata.timedata.dB_t=timedata(:,2); % [V]
    rawdata.timedata.dI_t=timedata(:,3); % [V]
    rawdata.timedata.Photo=timedata(:,4); % [V]
% Save structure to mat file
    download_time=datestr(now);
    shot_file_name=strcat('shot_data/',shot_nr_str,'.mat');
    save(shot_file_name,'rawdata','download_time')
end
```

3.3. Appendix No.4.: Matlab script for evaluation purposes

```
function script(shot,xmax)
close all
R0=0.4;
a=0.085;
mu0=4*3.141592654*1e-7;
dt=1e-5;

% Download data from URL
data=GOLEM_get_data(shot);

% Integrate and multiplie raw B_t
Btor=zeros(3000,1);
data.timedata.dB_t(:)=data.timedata.dB_t(:)-sum(data.timedata.dB_t(1:450))/450;
Btor(1)=170*data.timedata.dB_t(1)*1e-5;
for x=2:3000
        Btor(x)=Btor(x-1)+170*data.timedata.dB_t(x)*1e-5;
end

% Integrate and multiplie raw I_tot
Itot=zeros(3000,1);
data.timedata.dI_t(:)=data.timedata.dI_t(:)-sum(data.timedata.dI_t(1:450))/450;
Itot(1)=5000*data.timedata.dI_t(1)*1e-5;
for x=2:3000
        Itot(x)=Itot(x-1)+5000*data.timedata.dI_t(x)*1e-5;
end
% Offset setting
Itot(:)=Itot(:)-sum(Itot(500:500+data.time_delay/0.00001))/(data.time_delay/0.00001);
Itot(:)=Itot(:)*1000;
Itot(1:550)=0;

% Estimation of vacuum chamber parameters
UL=data.timedata.U_l;
dItot=zeros(3000,1);
for x=1:2999
dItot(x)=(Itot(x+1)-Itot(x))/dt;
end

% Plotting range
xmin=500+data.time_delay/0.00001;

% Plot of L_ch
plot(UL/dItot)
title(['L_{ch}' '  shot: ' num2str(shot)]),xlabel('t [1e-5 s]'),ylabel('L_{ch} [H]')
hold on
plot(Itot,'-r')
axis([xmin xmax -inf inf])
legend('L_{ch}','I_{tot}');
hold off
pause

% Plot of R_ch
plot(UL/Itot)
title(['R_{ch}' '  shot: ' num2str(shot)]),xlabel('t [1e-5 s]'),ylabel('R_{ch} [Ohm]')
hold on
plot(Itot,'-r')
axis([xmin xmax -inf inf])
legend('R_{ch}','I_{tot}');
hold off
pause

% Single best estimate of the chamber parameters for further calculations
Lch=2.01e-6;
Rch=9.8e-3;
```

```
% Plot of loop voltage to determine maximum value
% Plot of loop voltage to determine maximum value
plot(UL),title(['U_l' '  shot: ' num2str(shot)]),xlabel('t [1e-5 s]'),ylabel('U_l [V]')
hold on
plot(Itot/100,'-r')
axis([xmin xmax 0 inf])
legend('U_l','I_{tot}/100');
hold off
pause

% Solving the differential equation for I_ch
Ich=zeros(3000,1);
Ich(1)=Itot(1);
UL=data.timedata.U_l;
for t=2:3000
    Ich(t)=UL(t-1)*dt/Lch+(1-Rch*dt/Lch)*Ich(t-1);
end

% Calculating I_pl
Ipl=Itot-Ich;

plot(Ipl)
title(['I_{pl}' '  shot: ' num2str(shot)]),xlabel('t [1e-5 s]'),ylabel('I_{pl} [A]')
axis([xmin xmax 0 inf])
legend('I_{pl}');
pause

% Calculating R_pl
Rpl=zeros(3000,1);
for t=2:3000
% L_pl = 0 approximation
    Rpl0(t)=(UL(t)-0*(Ipl(t)-Ipl(t-1))/dt)/Ipl(t);
% L_pl = L_ch approximation
    Rpl(t)=(UL(t)-Lch*(Ipl(t)-Ipl(t-1))/dt)/Ipl(t);
end
Rpl=smooth(Rpl,0.05,'rlowess');

% Ohmic heating power
Poh=zeros(3000,1);
Poh=Rpl.*Ipl.^2;

plot(Poh)
title(['P_{OH}' '  shot: ' num2str(shot)]),xlabel('t [1e-5 s]'),ylabel('P_{OH} [W]')
hold on
plot(Ipl,'-r')
axis([xmin xmax 0 inf])
legend('P_{OH}','I_{pl}');
hold off
pause

% Central electron temperature
Tel=zeros(3000,1);
Zeff=1.5;
Tel=((R0/a^2*8*Zeff/1.544e3)^(2/3))*abs(Rpl).^(-2/3);

plot(Tel)
title(['T_{e0}' '  shot: ' num2str(shot)]),xlabel('t [1e-5 s]'),ylabel('T_{e0} [eV]')
axis([xmin xmax 0 100])
hold on
plot(Ipl/500,'-r')
legend('T_{e0}','I{pl}/500');
hold off
pause
```

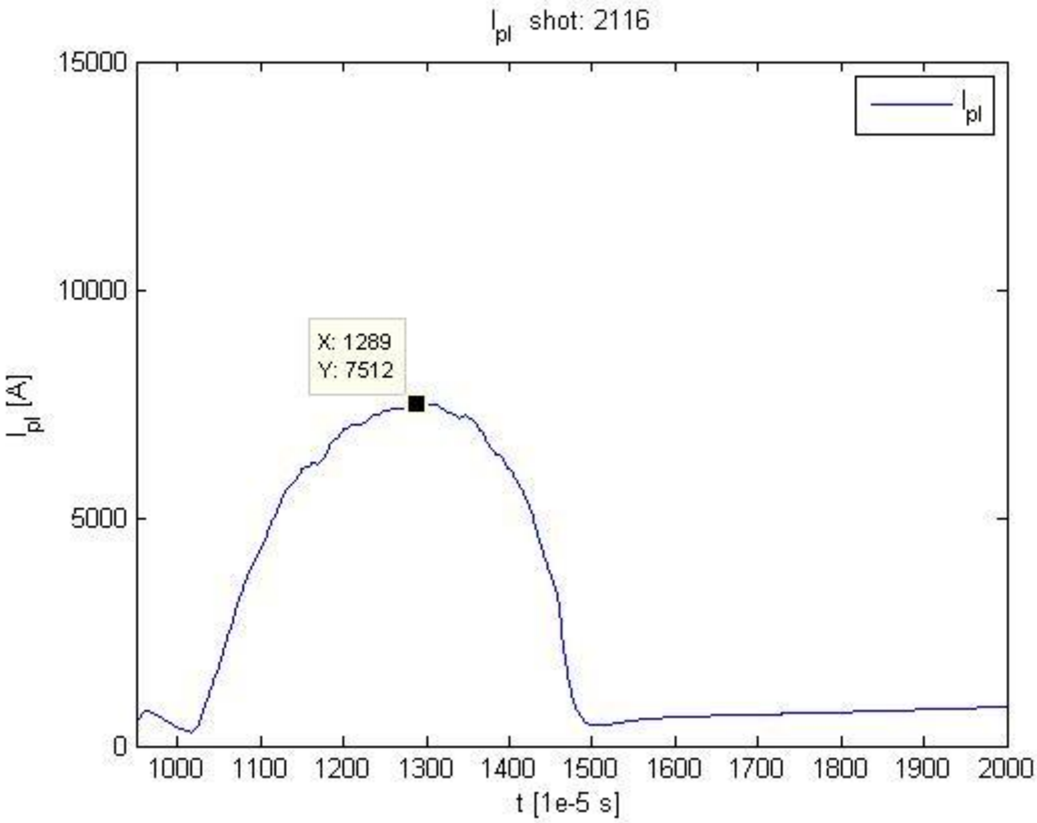
```
% q
q=zeros(3000,1);
q=a^2/R0*2*3.141592654/mu0*(Btor./Ipl);

plot(q),title(['q' '  shot: ' num2str(shot)]),xlabel('t [1e-5 s]'),ylabel('q')
axis([xmin xmax 0 20])
hold on
plot(Ipl/500,'-r')
legend('q','I_{pl}/500');
hold off
pause

% 1/q and Murakami-like parameter for Hugill diagram

% Manual setting of parameters
murmin=800;
murmax=1500;

recq=zeros(3000,1);
recq=q.^(-1);
recq(1:murmin)=0;
recq(murmax:end)=0;

mur=zeros(3000,1);
pch=data.pressure;
for x=1:3000
mur(x)=pch/100*0.4/Btor(x);
end
mur(1:murmin)=0;
mur(murmax:end)=0;

plot(mur,recq,'ro','LineWidth',1,...
                'MarkerEdgeColor','k',...
                'MarkerFaceColor','g',...
                'MarkerSize',3)
title(['Hugill' '  shot: ' num2str(shot)]),xlabel('Murakami'),ylabel('1/q')
% Manual setting of parameters
axis([0.5 1.5 0 0.5])
legend('Hugill');
pause

close all
```

3.4. Appendix No.5.: Shot summary table

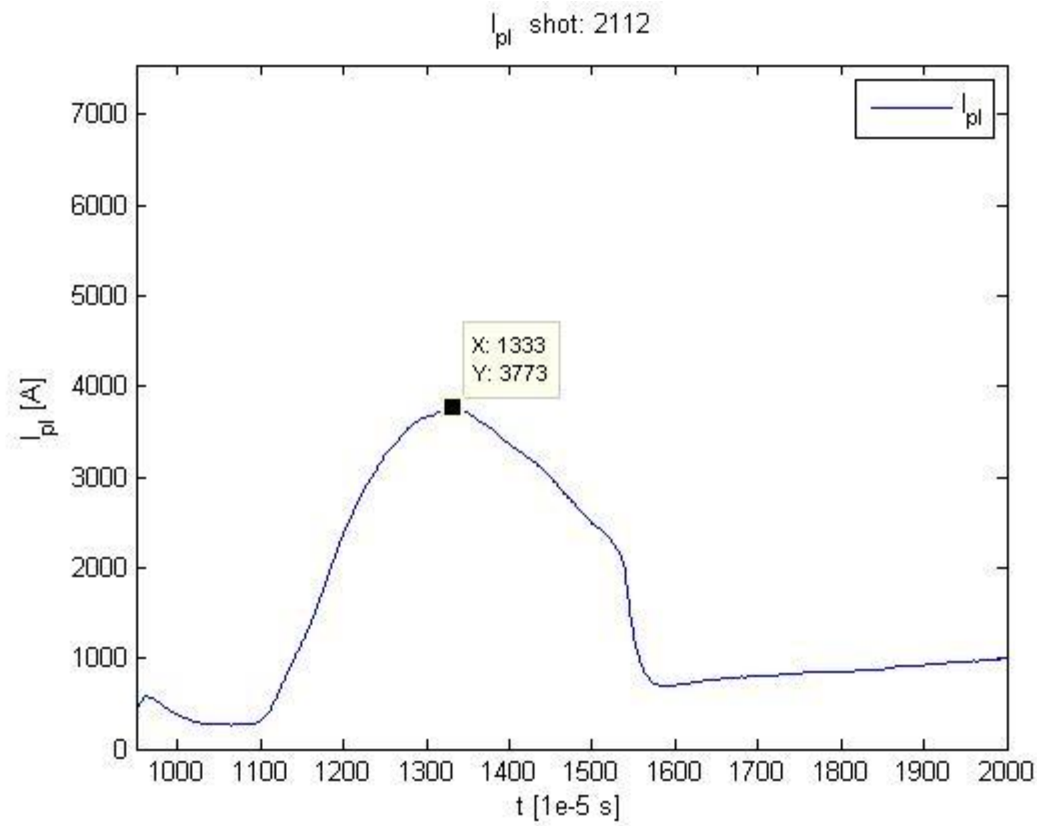
	No.	p_{ch} [mPa]	I_{pl}^{max} [A]	P_{OH}^{max} [kW]	T_{e0}^{max} [eV]	n_{avg} [m^{-3}]	W_{pl}^{max} [J]	τ_e [ms]	q^{max}
Test shots	2087	85,50	3222	43,50	28,4	4,16E+19	3,596	0,0827	7,20
	2088	84,52	3305	47,60	29,8	4,11E+19	3,730	0,0784	9,01
	2089	85,50	3674	52,05	31,0	4,16E+19	3,925	0,0754	8,55
1. loop	2090	85,50	-	-	-	-	-	-	-
	2091	82,28	3540	52,22	30,6	4,00E+19	3,734	0,0715	8,78
	2092	81,34	6675	117,90	29,8	3,96E+19	3,590	0,0304	4,71
	2093	-	-	-	-	-	-	-	-
2. loop	2094	82,28	-	-	-	-	-	-	-
	2095	81,65	-	-	-	-	-	-	-
	2096	81,03	-	-	-	-	-	-	-
	2097	81,03	4277	48,81	31,5	3,94E+19	3,780	0,0774	7,45
3. loop	2098	75,04	-						-
	2099	82,28	-	-	-	-	-	-	-
	2100	-	-	-	-	-	-	-	-
	2101	67,40	3011	28,35	27,4	3,28E+19	2,730	0,0963	10,3
	2102	-	-	-	-	-	-	-	-
	2103	94,03	-	-	-	-	-	-	-
	2104	56,27	3480	34,58	30,5	2,74E+19	2,538	0,0734	9,04
	2105	78,28	3030	30,49	26,4	3,81E+19	3,059	0,1003	10,4
	2106	93,04	1589	17,20	16,4	4,52E+19	2,260	0,1314	18,9
	2107	53,12	4091	43,41	31,3	2,58E+19	2,458	0,0566	7,64
	2108	76,79	3789	39,30	30,3	3,73E+19	3,444	0,0876	8,30
	2109	-	-	-	-	-	-	-	-
	2110	52,92	4475	49,22	33,0	2,57E+19	2,586	0,0525	7,18
	2111	77,98	3556	40,20	27,3	3,79E+19	3,147	0,0783	8,92
	2112	93,04	3773	43,94	28,6	4,52E+19	3,939	0,0897	8,50
1. loop	2113	78,28	4574	57,62	29,2	3,81E+19	3,382	0,0587	6,87
	2114	93,40	4616	62,28	28,8	4,54E+19	3,986	0,0640	6,81
	2115	60,30	7269	136,20	33,4	2,93E+19	2,978	0,0219	4,25
	2116	93,40	7512	150,80	33,8	4,54E+19	4,670	0,0310	4,20
2. loop	2117	66,37	6941	129,40	36,3	3,23E+19	3,570	0,0276	3,83
	2118	75,62	7008	101,10	35,1	3,68E+19	3,931	0,0389	4,58
	2119	73,33	7797	112,80	38,9	3,57E+19	4,223	0,0374	3,78
	2120	62,42	6678	97,76	34,6	3,04E+19	3,198	0,0327	3,84
	2121	63,38	3833	90,04	17,7	3,08E+19	1,658	0,0184	4,51
	2122	70,30	4929	119,90	21,4	3,42E+19	2,231	0,0186	4,08
	2123	72,49	7521	118,50	41,1	3,53E+19	4,417	0,0373	4,08
3. loop	2124	67,70	4225	105,80	19,5	3,29E+19	1,951	0,0184	3,35
	2125	70,57	5978	121,00	27,5	3,43E+19	2,873	0,0237	3,96
	2126	62,66	8323	117,90	40,8	3,05E+19	3,785	0,0321	3,72
1. loop	2127	72,22	4302	102,00	18,6	3,51E+19	1,992	0,0195	3,51
	2128	64,61	4418	123,00	19,3	3,14E+19	1,844	0,0150	3,31
	2129	66,11	3960	90,53	26,9	3,22E+19	2,638	0,0291	3,72
2. loop	2130	71,39	4537	115,00	20,2	3,47E+19	2,135	0,0186	3,41
	2131	68,97	3876	98,52	16,5	3,35E+19	1,686	0,0171	3,67
	2132	66,37	2337	92,27	8,7	3,23E+19	0,854	0,0093	3,38
3. loop	2133	3,92	-	-	-	-	-	-	-
	2134	3,73	-	-	-	-	-	-	-
	2135	3,70	-	-	-	-	-	-	-
4. loop	2136	41,23	3978	96,65	18,5	2,01E+19	1,127	0,0117	3,91
	2137	44,52	3251	59,04	14,6	2,17E+19	0,963	0,0163	4,29
	2138	40,45	2234	158,30	5,3	1,97E+19	0,317	0,0020	3,60

3.5. Appendix No.6.: Time traces of plasma parameters

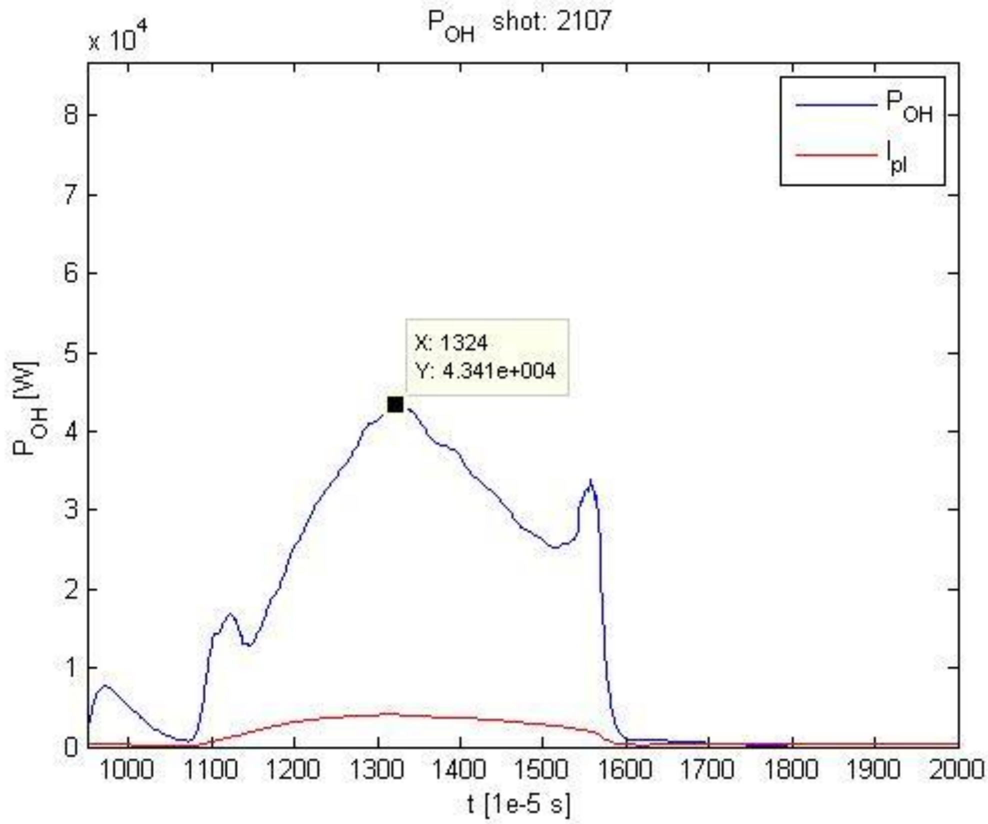
Plasma current, shot 2116:



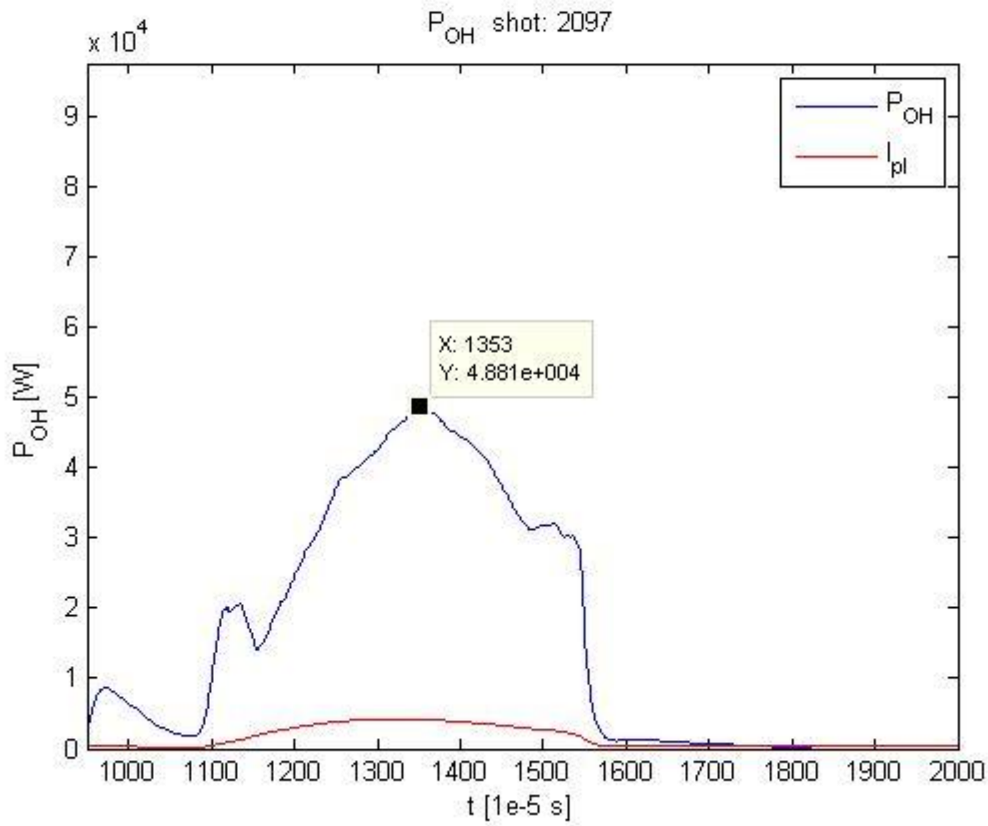
Plasma current, shot 2112:



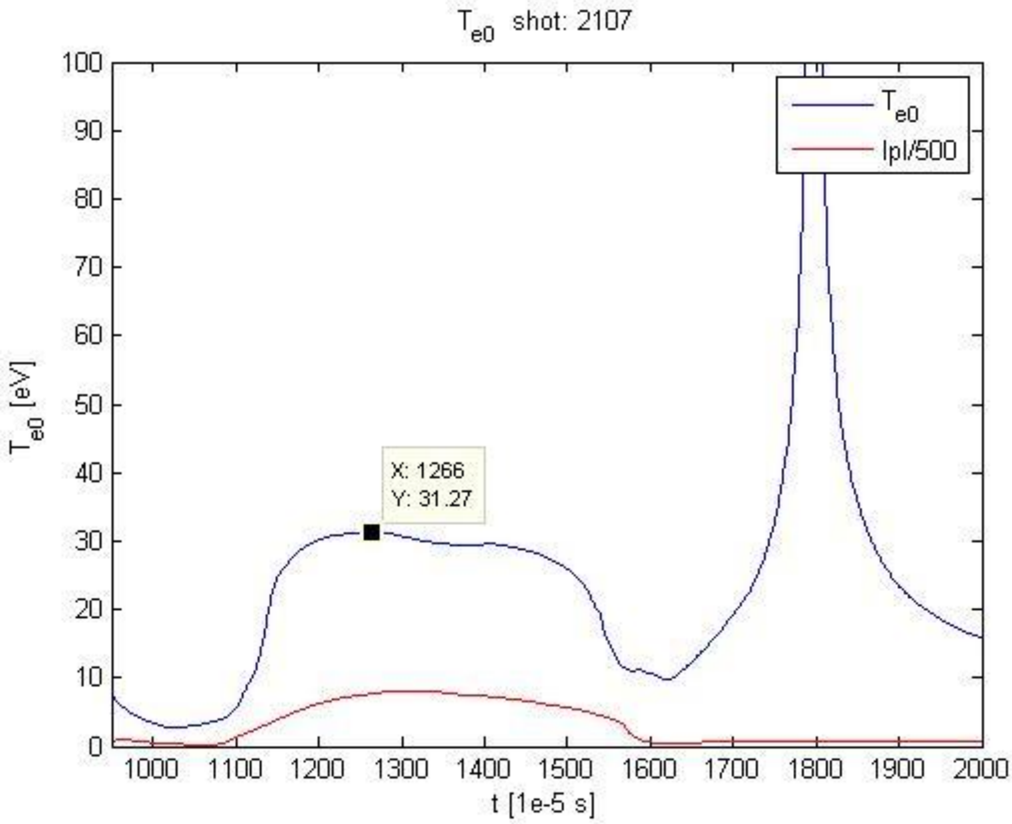
Ohmic heating power, shot 2107:



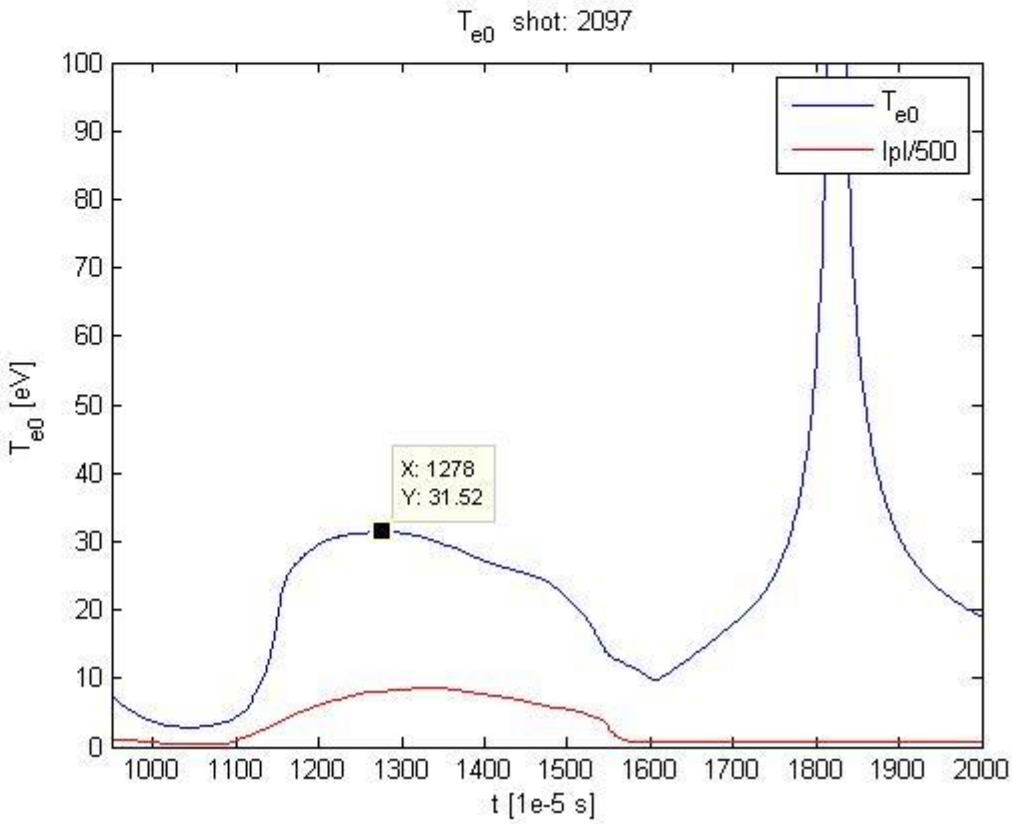
Ohmic heating power, shot 2097:



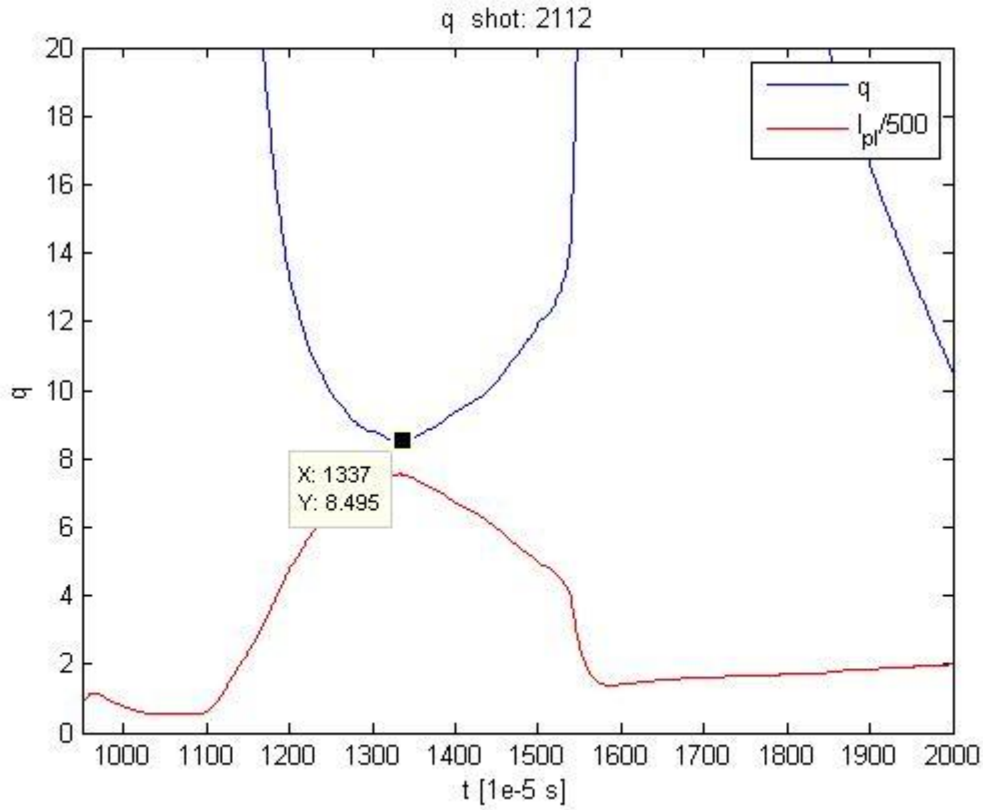
Central electron temperature, shot 2107:



Central electron temperature, shot 2097:



Edge safety factor, shot 2112:



Edge safety factor, shot 2091: