Proposal for a GOLEM experiment from BME-NTI

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Chapter 1

Introduction

This paper intends to give an overview on a possible measurement for students on GOLEM tokamak. Our aim is to make some basic tokamak measurements for students those are at the nuclear field within the confines of the so called special laboratories subject, about three times a semester. For this reason and to acquaint the students with the basics of plasma physics and the GOLEM tokamak device, we will make a quite detailed description to the measurement in Hungarian and maybe in English language. First of all, we would like to make all the measurements, those will be introduced in this paper. After the evaluation of the data, we would like to introduce our results for our colleagues, and pick the final tasks for the student measurements.

1.1 Capabilities of GOLEM

The GOLEM is a small size tokamak device with basic controls and diagnostics. It is ideal to acquaint students with tokamak operation and magnetically confined plasmas.

The parameters we would like to change during our session:

- Toroidal magnetic field (B_t) through the voltage of the toroidal field capacitor bank (U_B).
- Toroidal electric field (E_t) through the capacitor bank for the ohmic heating (U_E).
- Vessel pressure through the vacuum system (P_v).
- Hydrogen gas pressure (P_{H2}).
- The time delay between the triggers of the toroidal field and the ohmic heating (τ).
- The temperature of the vacuum chamber (T_{ch}).

The diagnostics we would like to use during our session:

- All magnetic diagnostics those are available.
- Photocell.

Chapter 2

Proposed experiments

We can set the initial pressure(p_{H2}), the voltages of the capacitor banks (U_B for the toroidal magnetic coil capacitor banks and U_E for the inductive current driving) and the time delay between the thyristor switches (τ, the magnetic field is switched on first).

2.1 Vacuum shot(s)

During a vacuum shot, when no plasma is formed, it is possible to determine the resistance of the vacuum vessel: all the current measured by the Rogowski-coil flows in the vessel. This is an important parameter for further evaluations.

Let us denote the loop voltage with U_l, the resistance of the chamber with R_{ch}, the total current (which is the chamber current (I_{ch}) in this case) with I_{tot} and the inductance of the chamber with L_{ch}.

The circuit equation is then

$$U_l = R_{ch} \cdot I_{tot} + L_{ch} \frac{dI_{tot}}{dt}. \tag{2.1}$$

Using the loop voltage measurement and the Rogowski-coil, we have both U_l and I_{tot} measured. The behavior of the current can be described by only the loop voltage, if R_{ch} and L_{ch} is known (by using the previous differential equation).

If we assume the inductance to be small, then the resistance of the chamber can be calculated easily, but it might be possible to determine the value of L_{ch} as well.

For this measurement almost any setting will do, the important thing is not to have a plasma discharge, so a large value of U_E and a small, or zero value of U_B should be used, with low hydrogen pressure.

2.2 Vacuum shots with heated chamber

The tokamak has an inductive heating system, mainly for baking the vacuum vessel, but it can also be used to alter the resistance of the chamber. We propose heating up the chamber with the baking system, and doing vacuum shots. This way we can measure the chamber resistance at different chamber temperatures. This way, calculations of measurement 2.1 can be checked.

2.3 Plasma measurements

The goal of these measurements is the drawing of the Hugill diagram for GOLEM. The Hugill-diagram consists of points on a plane, each of them representing a successful plasma discharge. The y coordinate of each point is the normalized current ($\frac{1}{q_{edge}}$) and the x coordinate is the normalized density ($n_e \frac{R_0}{B_t}$).

But we can not set these parameters directly, we can only assume, that increasing U_E will increase the normalized current, of course increasing U_B will decrease the normalized density.

So during this measurement we will vary U_B and U_E, decide if there was a plasma discharge at each shot, and if there was, we can can calculate these parameters, and put it on the Hugill-diagram.

The safety factor on the edge can be calculated approximately (on large aspect-ratio circular devices, like GOLEM):

$$q_{edge} = \frac{a_0}{R_0} \frac{B_t}{B_p} = \frac{a_0^2}{R_0} \frac{2B_t\pi}{\mu_0 I_p}. \tag{2.2}$$

For the toroidal magnetic field we have a choice: we can use the toroidal field measurement coil or we can calculate it.

During the evaluation we would like to calculate an effective temperature (based on Spitzer's resistivity formula[1]) and the Ohmic heating power (based on the plasma current (I_{pl}) and the calculated resistance of the plasma). By knowing the effective temperature and the density of the plasma, we can calculate it's energy content. The supplied power is only Ohmic heating, so during a quasi flat-top the energy-confinement time can be estimated from the measured parameters.

By assuming a current/temperature profile[2], we can also tell the profile of the safety factor, resistivity and the Ohmic heating power: we divide the plasma to 'layers', and each layer has it's own parametes. These layers are assumed to have a circular cross section, and the Shafranov-shift is neglected. We also neglect the current diffusion. This way, we should get a more precise approximation of plasma parameters then by taking just one effective value instead of the profiles.

This measurement should be carried out by scanning U_E and U_B, while keeping p_{H2} and τ constant. We would like to make as many measurements as we can, at least 25-30. Could be repeated at different p_{H2} and τ values.

2.4 Summary

In short, we would like to measure and calculate the following plasma parameters:

- Chamber resistance and internal inductance
- Chamber resistance variation by elevated temperatures

- Safety-factor (edge and profile)
- Temperature (mean and/or profile)
- Ohmic heating power (total and profile)
- Energy confinement time
- Hugill-diagram

Chapter 3

Proposed shots

#	p_{H2} [mPa]	U_B [V]	U_E [V]	τ [us]	notes
1-4	pump limit	minimal (400)	100,300,500,700	0	normal vacuum shot
5-8	40	400	100,300,500,700	1000	
9-12	40	600	100,300,500,700	1000	
13-16	40	800	100,300,500,700	1000	
17-20	40	1000	100,300,500,700	1000	
21-24	pump limit	minimal (400)	100,300,500,700	0	T_{ch}+50K
25-28	pump limit	minimal (400)	100,300,500,700	0	T_{ch}+100K
28-32	pump limit	minimal (400)	100,300,500,700	0	T_{ch}+150K

Shots 5-20 could be repeated to get better voltage resolution or with a different pressure and time delay.

Bibliography

[1] *NRL plasma formulary.* Naval Research Laboratory, 2009.

[2] Jana Brotánková. *Study of high temperature plasma in tokamak-like experimental devices.* PhD thesis, Charles University in Prague, 2009.