0.1 Diagnostics overview

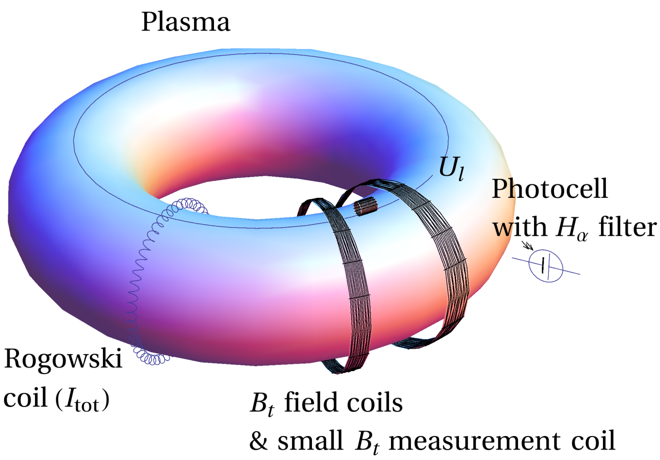

Figure 1: Tokamak diagnostics used in this assignment.

In tokamak research, the plasma is closely watched and controlled by a set of diagnostics. Figure 1 shows four basic tokamak diagnostics:

- A wire loop laid toroidally along the plasma ring: measures the **loop voltage** U_l.
- A small coil attached to the vessel, its axis in the toroidal direction: measures the time derivative of the **toroidal magnetic field** dB_t/dt.
- A Rogovski coil tied around the vessel: measures the time derivative of the total poloidal magnetic field dB_p/dt. The poloidal field consists of two contributions: (i) the field generated by the **plasma current** I_p, and (ii) the field generated by the current I_{ch} running through the tokamak chamber, induced by the loop voltage along with the plasma current.
- A photodiode with an H_α filter: measures the radiation intensity of the H_α spectral line (a dominant line in the hydrogen spectrum).

An example of the time evolution of these quantities is shown in figure 2, with the addition of the line-averaged electron density measured by an interferometer. The quantities marked in the bold face are the ones you will process for each discharge to calculate the plasma parameters. Each of the three diagnostics, the wire loop, the measuring coil, and the Rogowski coil, has its own particular signal processing. This is explained in the following sections.

0.2 Wire loop

The wire loop signal requires no post-processing (beside offset removal if needed; see section **??**). The loop voltage U_l is the direct output of channel 1 measurement.

0.3 B_t measuring coil

According to Faraday's law of induction, if the magnetic flux passing through a conductive loop changes, a voltage U is induced on it. Assuming that the loop is small so the magnetic field inside it is uniform, the voltage magnitude is

$$U = NS\frac{dB_\perp}{dt} \tag{1}$$

where N is the number of the coil threads ($N = 1$ for a single loop), S is the loop area and $B_\perp$ is the magnetic field component perpendicular to the loop area.

Electromagnetic induction is also the principle of the B_t loop measurement: the coil is simply placed into the magnetic field, its axis pointing along the toroidal direction, and its signal (the voltage U_{B_t}) is integrated in time and calibrated. The calibration constant is theoretically equal to NS; however, in this assignment you will calibrate the signal by comparing the toroidal magnetic field B_t measured by the standard GOLEM diagnostic set to your own measurements of $\int_0^t U_{B_t}(\tau)d\tau$.

$$B_t(t) = C_{B_t}\int_0^t U_{B_t}(\tau)d\tau \tag{2}$$

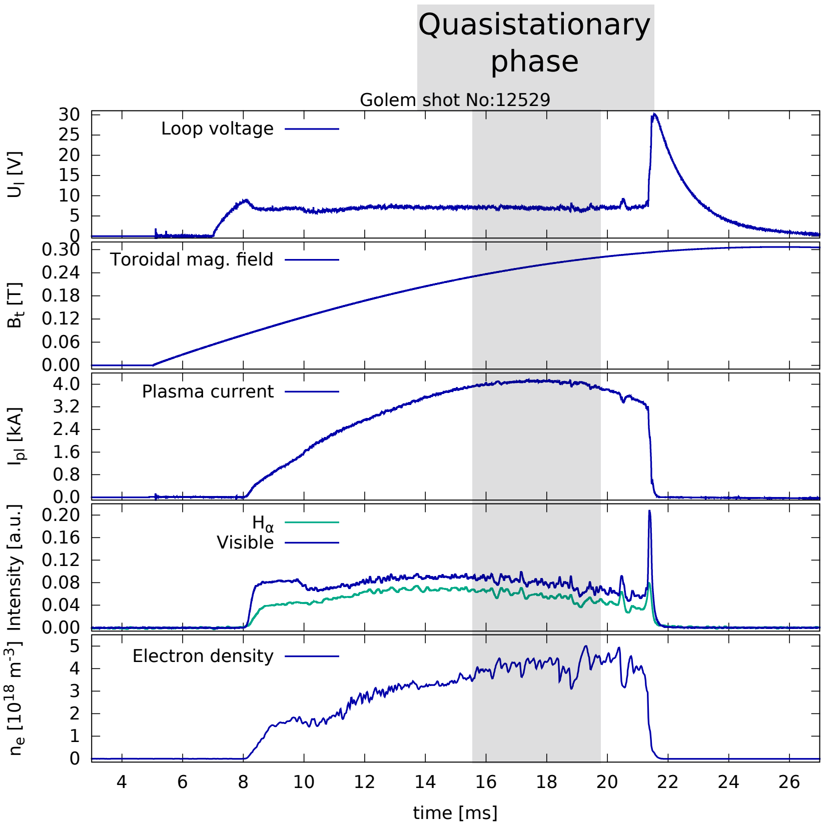

Figure 2: Time evolution of a well executed GOLEM discharge. From top to bottom - loop voltage U_l, toroidal magnetic field B_t, plasma current I_p, H_α spectral line intensity and line-averaged electron density n_e.

This calibration may be done individually for every individual discharge, but it is more convenient to calculate the calibration constant C_{B_t} once and then reuse it. (Note, however, that every B_t coil is placed differently and so calibration constants of distinct coils will be different.)

0.4 Rogowski coil

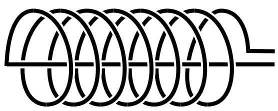

Figure 3: Rogowski coil scheme.

The Rogowski coil is the most complicated of the three self-implemented diagnostics whose signal you will post-process. It is a "coil loop" — a one-metre long thin coil which is wrapped around the tokamak chamber poloidally. As seen in figure 3, one of the Rogowski coil ends is directly accessible, while the other leads through the coil to negate the toroidal magnetic field contribution in its signal. As a result, the coil only picks up the poloidal magnetic field via electromagnetic induction,

$$U_{RC} \propto \frac{dB_p}{dt}.$$

The poloidal magnetic field has two components: the field $B_{p,p}$ generated by the plasma current I_p and the field $B_{p,ch}$ generated by the toroidal current I_{ch} induced by the loop voltage in the tokamak chamber. The respective currents are then proportional to their magnetic field according to the Biot-Savart law. The chamber current contribution is unwanted and has to be removed in order to find the plasma current I_p. Luckily, I_{ch} can be easily calculated using the loop voltage and the chamber resistivity, $I_{ch}(t) = U_l(t)/R_{ch}$ where $R_{ch} = 0.0097\,\Omega$. The calibration constant C_{RC} can then be defined with the relation

$$I_p(t) + \frac{U_l(t)}{R_{ch}} = C_{RC} \int_0^t U_{RC}(\tau) d\tau \tag{3}$$

and calculated from the standard diagnostic output on the left-hand side and the oscilloscope data on the right-hand side. With C_{RC} and R_{ch} known, the plasma current can finally be calculated from the oscilloscope data as

$$I_p(t) = C_{RC} \int_0^t U_{RC}(\tau) d\tau - \frac{U_l(t)}{R_{ch}}. \tag{4}$$