Plasma fluctuations in tokamak discharges

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Abstract:

This work discussed the analysis of tokamak discharges. Its goal was to determine fluctuations of plasma properties. It also contains basic instructions to help estimate discharge input, so the investigation of plasma´s properties in tokamak discharges can be continued and reproduced in the future.

Introduction

Our goal was to learn how to recognize different types of plasma fluctuations and oscillations, using various analysis methods, including Fourier analysis and measurement error theory.

This research wouldn´t be possible without a tokamak. A Tokamak is a device that creates a toroidal magnetic field, used as a magnetic container for storing high-temperature plasma. This type of device was invented to harvest nuclear-fusion power.

We were collecting data at the local tokamak GOLEM at the Czech Technical University in Prague. We were able to see different types of fluctuations and record their data. The primary objective of this experiment is to identify the types of plasma oscillations present in tokamak shots. Turbulent flows are the main transport mechanism in the magnetic helical field in the tokamak. These appear in most signals as continuous fluctuations with a wide range of frequencies. The transport in tokamaks is sometimes transient, appearing only as short-time bursts in fluctuations. The plasma waves can also contribute to the fluctuations, having a long-time duration and a well-defined frequency.

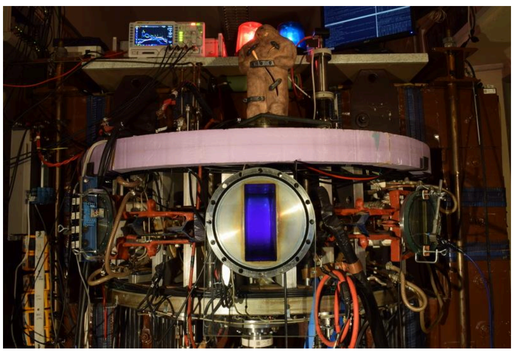

Figure 1: Tokamak GOLEM

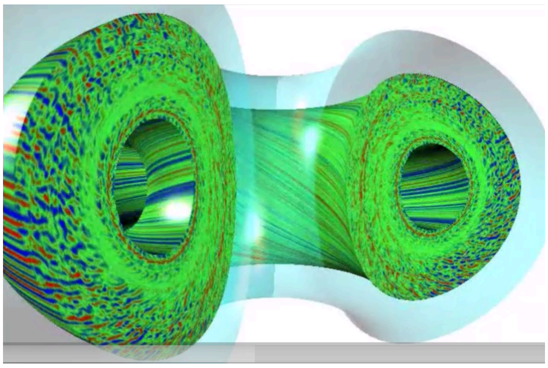

Figure 2: Numerical simulation of plasma turbulence of DIII-D tokamak by GYRO code

Body of miniproject

1.1. Materials and methods

During this research, we utilized GOLEM with the help of a page dedicated to the use (aka Tokamak remote Control room). Crucial for embodying what happened in the tokamak during shots and characteristic of plasma, was Python, more exactly Jupyter. We gathered our data from the Tokamak GOLEM plasma parameters page, which unveiled all the important sets of information. For the assessment of plasma fluctuations, Mirnov coils are required.

1.2. Results - data analysis

In the future, the plasma stream in fusion reactors should be as stable as possible to prevent the chamber from any damage and extend the confinement.

1.2.1 Discharges with plasma

Via remote access to a controller of the tokamak Golem we were able to set the parameters for the discharges in subsequent tables. We aimed to imitate shots produced in the work of Tomáš Markovič [1].

Plasma discharges	Toroidal field capacitor U_Bt [V]	Current drive capacitor U_cd [V]	Current drive delay t_cd [us]	Gass pressure p_H [mPa]	Actual gass pressure p [mPa]
#49321	800	450	1000	10	9.89
#49325	585	400	1000	10	9.95
#49328	585	400	1100	15	14.8
#49341	585	400	2000	15	14.8

Plasma discharges	Plasma lifetime t_p [ms]	Maximum toroidal field B_t [T]	Maximum plasma current I_pmax [kA]	Safety factor q_a	Maximum average temperature of electrons T_e [eV]
#49321	13.16	0.39	5.07	6.083	65.442
#49325	14.66	0.32	7.48	3.757	138.412
#49328	14.54	0.32	6.82	4.041	121.032
#49341	13.81	0.32	5.96	4.843	97.982

Table 1+2: Input of shots used for discharges with plasma

In Tables 1 and 2, we have summarized the basic properties of the discharges we performed on the Golem tokamak, which successfully contained plasma.

One of the main targets of our attention was 16 Mirnov coils, whose task is to get an overview of plasma fluctuations. Mirnov coils register magnetic field perturbations. Throughout the remote access site, we gathered information about Mirnov coils.

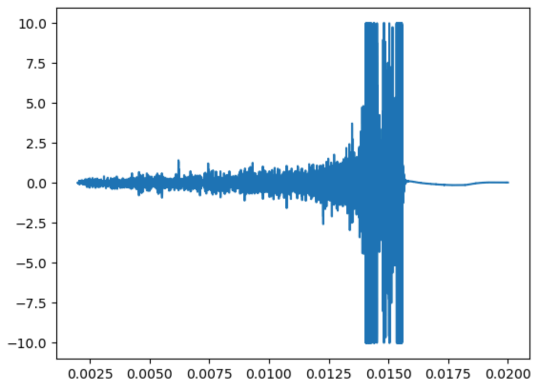

Figure 3: Raw signal measured from Mirnov coil 15, shot number 49328.

Figure 3 shows the raw signal of our most successful shot. We can observe non-constant amplitude, and the signal amplitude is starkly increasing toward the end.

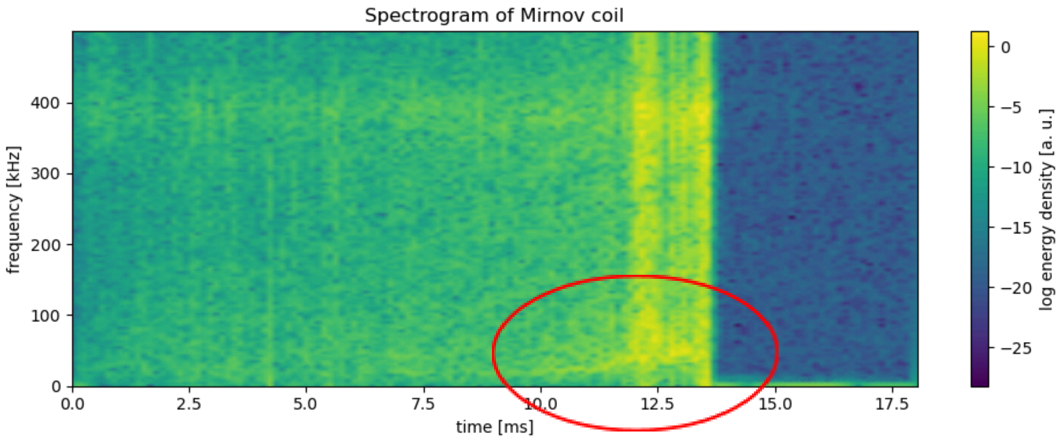

Figure 4: Spectrogram of the data from the raw signal absorbed from 15th Mirnov coil of the discharge number 49328. The most prominent narrow-band oscillation of coils in our attempts is encircled.

The spectrogram in Figure 4 is a product of windowed Fourier analysis applied to the raw data (Figure 3). These kinds of oscillations are observable: narrow-band (horizontal = constant frequency, long-time period), broad-band fluctuations (scattered everywhere), and bursts (vertical = very-short time period, changing frequency).

The most important for our analysis are the narrow-band oscillations indicating a high degree of synchronization and coherent magnetic field. The most prominent oscillation is located between 10 and 13.75 milliseconds of the discharge. This oscillation has a continuously rising frequency, ranging from 15 to 60 kHz, and exhibits the highest level of energy density for a short period during this shot. Narrow-band oscillations, unlike broad-band ones, are approximately concentrated around one frequency. Towards the end of the discharges (as shown in the graph in Figure 4), the frequency of oscillations increases. This phenomenon signifies the similarity to discharge number 10579 of Tomáš Markovič [1].

1.2.2. Discharges without plasma

No Plasma	Toroidal field capacitor U_Bt [V]	Current drive capacitor U_cd [V]	Current drive delay t_cd [us]	Gass pressure p_H [mPa]	Actual gass pressure p [mPa]
#49330	585	400	11000	15	14.9
#49334	585	400	5500	15	10.1
#49314	370	550	1000	10	14.8
#49320	370	550	1100	10	10.1

Table 3: Input of shots used for discharges without plasma

Failed attempts are shown in Table 3. Despite trying to follow input properties, half of our shots failed due to a lack of convenient conditions prerequisite for plasma creation, pinpointing the importance of short current drive delay and sufficient voltage in both capacitors.

1.3. Discussion

When it comes to reproducibility, this experiment is not completely reproducible. Processes in tokamaks are self-governing, even discharges with the same input may have different results. Data and results can be reused in the next tokamak discharges. Valuable might be data from tables 1, 2 and 3 for determining what conditions should subsist in the chamber. Despite the hard reproducibility, we were successful in observing similar phenomena. Narrow-band plasma oscillations in our outcomes, indicative of a coherent field, were studyable.

Summary

This work´s aim was to estimate the behaviour of plasma fluctuation in the tokamak Golem during discharges. For detecting signals, we utilized 16 Mirnov coils, and for processing collected signals, we used the windowed Fourier analysis method. All three kinds of plasma oscillations (narrow-band, bursts and broad-band) were observable.

Acknowledgement

We would like to thank our supervisor, Mr. Gergo Pokol and the organizers of The Week of Science at Jaderka for letting us work on this project.

References

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