INTERFEROMETRIC PLASMA DENSITY MEASUREMENT IN GOLEM TOKAMAK

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INTRODUCTION

Electron density is on of the key parameters in the field of plasma physics. Its measurement provides important information about the behaviour and characteristics of plasma. For that purpose many different methods of density measurement exist.The most widespread are microwave diagnostics, mainly because of their non-invasive nature.

The microwave interferometer which has been recently installed at the GOLEM Tokamak measures the line-averaged electron density and can be used to track the time evolution during a discharge.This diagnostic had been previously implemented on the same device when it was in service as the CASTOR Tokamak at the Czech Academy of Sciences and the whole waveguide system and other analytical hardware were made with the specific parameters of the site and work-flow in mind. This paper presents the current state of implementation at the GOLEM Tokamak.

FUNDAMENTAL PRINCIPLES OF OPERATION

In ionized plasma oscillations of electrons around ions arise when the homogeneity of the electrostatic charge is disrupted. The angular frequency of such plasma oscillations ω_p is dependant on the electron density n_e.

As shown in [1], an electromagnetic wave propagating through plasma perpendicularly to the magnetic and electric field[1] has a dispersion relation

$$\omega = \omega_p + c^2 k^2 \qquad (1)$$

where ω is the angular frequency of the propagating EM wave, k is its wavenumber and c is the speed of light in vacuum.

Therefore an EM wave with a given angular frequency $\omega > \omega_p$ has a real wavenumber k and it propagates with a phase velocity $v_p > c$. Hence the refractive index n is less than 1 and is dependent on ω_p, thus also dependent on the electron density n_e.

As ω approaches ω_p, the refractive index n approaches 0 so the EM wave cannot propagate and is reflected. Thus for probing beam with a given ω there is a so called critical density n_{crit} above which the measurement cannot take place.

A microwave beam probing the plasma undergoes a phase shift $\Delta\varphi$ due to the different n. As n_e and therefore also n differs throughout the plasma, the total

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[1]a so called "ordinary wave", the geometry of a conventional Tokamak allows for such fields to exist

phase shift is directly proportional to the line integral of n_e over the distance d traveled through plasma as has been derived in [1]

$$\overline{n_e} = \frac{n_{crit}\lambda_0}{d\pi}\Delta\varphi \qquad (2)$$

where λ_0 is the wavelength of the microwave in vacuum and d is the distance that the microwave beam travels through plasma.

$\Delta\varphi$ is then extracted from the interference of the probing MW beam and the reference beam which was split off from the probing beam before entering plasma and thus has the same phase as the probing beam had before it entered plasma.

FREQUENCY MODULATION

The Gunn diode MW generator generates microwaves with frequencies $f \sim 75$ GHz. Analyzing the interference and extracting the phase shift at such high frequencies would be a very hard task and the time resolution obtained by analysing such high frequencies would be unnecessary as it it assumed that the density of plasma doesn't change as quickly.

Therefore, frequency modulation is used to scale down the time resolution of the analyzed signal. The frequency f of the microwaves generated by the Gunn diode can be scaled by applying external voltage. There is also a difference ΔL between the distance traveled by the reference wave and the probing wave as the reference wave travels several centimeters from the generator directly to the mixer diode where it interferes with the probing wave which had to travel several meters from the generator, to the chamber and back to the mixing diode.

This design results in beats when the two waves interfere, provided the frequency of the generated MWs is progressively scaled, because the waves will have different frequencies due to the difference in distances.

Ideally, f would be continuously linearly scaled up with a rate of change $\frac{df}{dt}$ which would result in a constant difference f_{diff} between the frequencies of the waves

$$f_{diff} = \frac{\Delta L}{c}\frac{df}{dt} \qquad (3)$$

Therefore, f_{diff} would be also the frequency of the absolute value of the amplitude of the beats.

However, the generated frequency can be scaled up only to a certain level, therefore the linear scaling slope has to be broken down to a periodic saw-tooth slope with an amplitude Δf and a frequency f_{mod}.

From (3) it can be derived that while

$$\Delta f = \frac{c}{\Delta L} \qquad (4)$$

it is true that $f_{mod} = f_{diff}$ and thus the frequency of the resulting beats can be controlled by applying a saw-tooth voltage signal with the right parameters to the generator.

The beat interference is then processed by a selective frequency band amplifier which amplifies signals with frequencies 500 ± 20 kHz. Therefore, the parameters of the saw-tooth voltage signal are $f_{mod} = 500$ kHz and ΔL is set for (4) to be true.

WAVEGUIDE MODEL

METHODS OF SIGNAL ANALYSIS

The output of the amplifier is a sine wave signal with a frequency f_{mod}. The phase shift can be extracted from it by either an analogue analysis circuit or digitally by first digitizing the signal with a Tektronix DPO 3014 oscilloscope and then processing on a computer.

The analogue circuit measures the time between the trigger signal and the roots of the sine signal. The trigger signal is synchronously generated by saw-tooth voltage generator with f_{mod}. However, the circuit compares only every eighth trigger signal, thus the sampling frequency of this method is only $62, 5$ kHz. The output of the circuit is voltage directly proportional to $\Delta\varphi$, $1V \sim 2\pi$. This output is digitized and then processed with (2).

The oscilloscope digitizes the signal with a sampling f. of 25 MHz. The data is then filtered for regions where the amplitude is close to 0, because there the amplitude dampening is assumed to be minimal. These regions are then fitted to $f(t) = A\sin(2\pi 5e5t + \varphi)$ and the fitted value of φ is further processed with (2).

SIGNAL DISTURBANCES

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