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MHD mode bispectral analysis from density fluctuations in Aditya discharges

P.K. Atrey[a,b,*], Dhaval Pujara[a], S. Mukherjee[b]

[a] *Institute of Technology, Nirma University Ahmedabad, Gujarat, India*
[b] *Institute for Plasma Research, Gandhinagar, Gujarat, India, India*

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ABSTRACT

The magnetohydrodynamic (MHD) modes and sawtooth activities are observed in many discharges in 100 GHz interferometer signal in Aditya tokamak. Two types of discharges are observed: one with a single dominant mode and the other with multiple modes during the current flat top of the discharge. Time frequency and the bispectral analysis of these discharges of the interferometer signals allow studies of mode coupling and its role in sustenance and termination of discharges. The role of mode coupling in determining the disruption phenomena in Aditya tokamak discharges using microwave interferometer diagnostics is reported.

1. Introduction

Structure of magnetohydrodynamic(MHD) modes has always been an interesting study in tokamak devices. It is well known that Mirnov oscillations with poloidal and toroidal mode numbers m and n, respectively, are created by perturbation of current channel on rational magnetic surfaces. The coherent structure of such rotating modes can be obtained by poloidal and toroidal arrays of Mirnov coils inside the tokamak vacuum vessel. In tokamak discharges, some of magnetohydrodynamic (MHD) modes (like large $m/n = 2/1$) are known to cause major disruption of plasma current. The detailed studies of these MHD modes were carried out in several tokamaks [1–7] and have been documented. Many theoretical models have also been proposed to identify the underlying causes of the disruption [8]. Although there could be several triggers for the disruption (for example increased radiation loss at high densities), the fact that ultimately, it is the MHD modes which play crucial role, is well recognized [9,10]. In particular, importance of growing poloidal mode $m = 2$ island has been recognized. Some reports also point out the role of interaction among low mode number MHD activities in causing the sudden loss of heat and particles from the tokamak.

In this paper, the observation and analysis of coherent mode MHD activity in Aditya tokamak [11] are being reported. Such studies using magnetic pick up coils have been reported earlier by Raju et al. [12]. Here the recorded signals from the microwave interferometer which is routinely used for the measurement of plasma density in Aditya tokamak, are being primarily considered. The observation of coherent modes in the interferometer signals is being related to rotating magnetic islands, which might cause filamentation of plasma current channel. The interaction among different mode frequencies is studied using bispectral analysis technique. The rest of the paper is organized as follows. In Section 2, the basic principle of microwave interferometer diagnostic is described followed by the experimental set-up for Aditya. In Section 3, the observed signals are presented and possible inferences are given. In conclusion, the finding based on results are summarized.

2. Microwave interferometer

2.1. Basic principle

An interferometer is used to measure the difference in traversed path length between a known medium (usually air/vacuum) and a beam transmitted through an unknown medium (here plasma), both of which are having same geometrical length. The actual path length through the plasma varies because of change in the refractive index, which itself depends on the electron density. Hence, if the path difference is known, one can derive the density information from that. The path difference is usually measured in terms of phase difference between the two beams, when both originate from the same source. For a typical density of Aditya tokamak plasma, the optimum frequency of the wave falls in the microwave range. For ordinarily polarized electromagnetic wave, the phase difference ϕ between the two beams caused by the presence of the plasma is given by [13]

* Corresponding author at: Institute for Plasma Research, Gandhinagar, Gujarat, India.
E-mail addresses: atrey@ipr.res.in (P.K. Atrey), dhaval.pujara@nirmauni.ac.in (D. Pujara), mukherji@ipr.res.in (S. Mukherjee).

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$$\varphi = \left(\frac{e^2}{2\varepsilon_0 m_e \omega c}\right)\int_0^l n_e(x)dx \tag{1}$$

For a path length l, the chord averaged electron density $\overline{n}_e$ can be written as

$$\overline{n}_e = \left(\frac{2\varepsilon_0 m_e c}{e^2}\right)\left(\frac{\omega\varphi}{l}\right) \tag{2}$$

where ω – the source frequency, ε_0 – the permittivity of free space, m_e – mass of the electron, c – velocity of light and e – charge of electron.

For a square law detector which has been used in microwave interferometer, the current is proportional to the square of microwave voltage at the diode terminals and hence to the microwave power. Thus, the detector signal, which is the sum of the reference and the transmitted signal, can be written as [14]

$$S(t) = \left(\frac{A^2 + B^2}{2}\right) + AB\cos(\varphi(t)) \tag{3}$$

where A and B are the amplitude of the signals in reference and transmitted paths, ϕ is the phase shift due to plasma. By knowing the phase shift ϕ due to the presence of plasma (Eq. (3)), the averaged electron density is calculated with the help of Eq. (2).

2.2. Experimental set − up

The Aditya [11] is a small size tokamak with major radius R = 75 cm and minor radius a = 25 cm. For this experiment, Aditya is operated at a toroidal magnetic field of ~ 0.75 T, with a neutral base pressure of ~ 3.5–5.0 × 10^{-5} Torr. The plasma current achieved is between 70 and 90 kA with the discharge durations being in the range between 60 and 120 ms. A 100 GHz interferometer is routinely used to measure the chord averaged electron density at the centre of Aditya tokamak. The measured chord averaged plasma density at the centre is in the range (1.5–2.5) × 10^{13} cm^{-3}. The block diagram of 100 GHz interferometer set-up is shown in Fig. 1. A Gunn Oscillator at 100 GHz with an output of 30 mW is used and the output power of the source is divided in two parts by using a 10 dB directional coupler. Signal from forward port of the directional coupler is taken to the horn at the bottom port and the other output as reference channel is directly connected to the mixer in the cabinet. The cabinet is situated 6.5 m away from the plasma centre. The receiving horns are placed at the top port of the vacuum vessel. The distance between the transmitting and receiving horn is 1.05 m. The ceramic lenses are fitted on the cover flanges, which focuses the microwave beams and are also used as vacuum windows. The wave-guide horns along with their supports are isolated electrically from the vacuum vessel and other supporting structures. The loss in W −band (WR – 10) wave guide is 5 dB/m and in the oversized wave guide K −band (WR – 42) at 100 GHz is 1 dB/m. Therefore, the oversized wave guide of 15 length is used in plasma path of each channel to reduce the losses in the wave guide paths. Transitions from W −band to K −band are used for each channel on either sides of plasma path. Wave guides WR − 10 are also used for reference channels. The phase detectors are made of magic tees, detectors and detector mounts. A variable attenuator (0–30 dB) is used in each reference channel to match the power in both the paths. A variable phase shifter (0–360°) is connected in the reference channel to adjust phase difference to zero between the reference and plasma path before the plasma discharge.

The output of the detector is amplified by using a low noise amplifier with a gain of 1000. The output of the amplifier is fed to INCAA digitizer through opto-coupler. A digitization rate of 100 kHz has been used to acquire the output signal of the interferometer. The phase shift ϕ and the density n_e are computed using Eq. (3) and Eq. (2) respectively.

3. Results and discussions

The set-up of 100 GHz microwave interferometer has one chord at the centre of Aditya, which is being operated regularly. In some of the raw signals from the interferometer, we observed some sawtooth activities (Fig. 2) and in other we observed coherent oscillations, resembling MHD oscillations. On more careful analysis of these oscillations, we observe two types of discharges from the point of view of MHD activities: (i) discharges with a single dominant mode frequency (type I) and (ii) those with strong mode coupling and presence of significant power at multiple frequency (type II).

Fig. 2 shows evolution of the plasma current, the chord averaged plasma density, the fringes in interferometer signal (at the central chord) and sawtooth activity on the interferometer signal of a typical discharge without any disruptive MHD activity. Interferometer signal means the output of the amplifier which has been used to amplify the square law detector signal. The sawtooth activity is observed in these

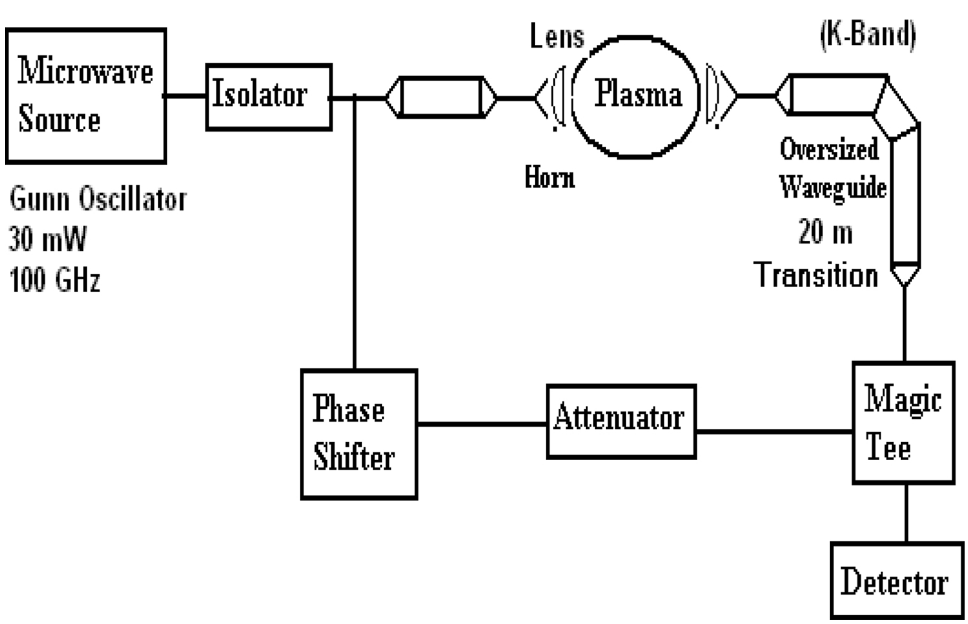

Fig. 1. Block diagram of the microwave Interferometer system.