A heterodyne Phase Contrast Imaging system for Ion Cyclotron Emission detection

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The Phase Contrast Imaging diagnostic on the DIII-D tokamak has been upgraded with a novel optical heterodyne detection scheme to detect electron density fluctuations at frequencies of tens of megahertz. The novel system can be employed to measure the radial structure of the electron density component of Ion Cyclotron Emission (ICE), thus extending the purely temporal measurements provided so far by magnetic probes. The heterodyne system considerably extends the frequency response of the PCI method by modulating the probing laser beam at a frequency close to that of the wave of interest, thus placing the detected beat wave within the frequency bandwidth of the detector array. The system employs ~~an~~ a variable frequency Electro-Optic modulator to allow operation at any frequency in the range 5–50 MHz, where most of the ICE harmonics are observed on DIII-D. The use of an EOM allows one to operate the system at various frequencies without the need to realign the system. The response of the EOM to the modulation frequency and the driving voltage is reported.

I. INTRODUCTION

Waves in magnetically confined plasmas is a broad and complex topic that has been the subject of intense theoretical and experimental investigations for nearly a century. Its extent can be appreciated by noting that oscillations span several orders of magnitude both in frequency, from kHz to hundreds of GHz, and spatial scales, from the electron gyro-radius to the size of the plasma itself, either as turbulent or coherent phenomena. The experimental characterization of the entire spectrum of waves is an extremely challenging task due to constraints in the measurements; such limitations can be of a technological nature, e.g. inadequate signal to noise ratio or spatio-temporal response of the apparatus in use, or due to the inability to detect a given component of the wave under consideration. In this work we expose a method to detect the spatio-temporal characteristics of a particular class of instabilities in the cyclotron range of frequencies, commonly referred to Ion Cyclotron Emission (ICE). First predicted in the 1950s[1–4], this class of waves is believed to be a Compressional Alfvén Eigenmode generated by anisotropies, or inversions, in the distribution function of energetic particles that causes emission of electromagnetic radiation in bands centered around the thermal ion cyclotron frequency, as well as higher harmonics[5]. While ICE was first observed in the late 1970s on the TFR tokamak[6], it sparked increasing interest in the fusion community only from the early 1990s thanks to its suitability as a passive diagnostic tool of the energetic ion population that is compatible with the harsh environment in future fusion reactors. As such, it was searched for and observed on many magnetically confined plasma devices[7–17] which detected emission caused by either supra thermal beam ions or fusion products. Although there exist numerous measurements of frequency spectra and toroidal mode numbers on various plasma discharge actuators, the radial and poloidal structure of the instability are still elusive because all the reported measurements were performed using either external magnetic loops or heating antennas operated in receiving mode, both of which are not capable of directly measuring the RF field components in the plasma core. More specifically, diagnostic systems that are usually employed to detect the radial or poloidal structure of a given instability cannot detect ICE because its frequency exceeds the diagnostic bandwidth. The system described in this work was conceived to fill such gap and provide further constraints to the theoretical description of the instability which is not yet complete, especially in the non-linear phase[18].

The paper is organized as follows: Section II gives an overview of the Phase Contrast Imaging method; the technical details of the heterodyne PCI for ICE detection are described in Section III; conclusions are offered at the end.

II. THE PHASE CONTRAST IMAGING METHOD

The Phase Contrast Imaging (PCI) method is an optical technique that uses probing light traveling through a transparent medium, and converts phase shifts induced on the probing wavefront into amplitude variations at the image plane. Invented in the 1930s by F. Zernike[19], who proved its superior sensitivity compared to competing methods used in cellular microscopy, its application to plasmas was pioneered by M. Presby and D. Finkelstein in the late 1960s[20] and its application to measure the dispersion of waves in fusion grade plasmas may be attributed to H. Weisen in that late 1980s[21]. In very simplistic terms, the

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