Measurement and analysis of density profiles in the island divertor region and in the plasma edge of W7-X

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Introduction

Microwave reflectometry is a non-intrusive plasma diagnostic tool which is widely applied in many fusion devices. The information of plasma electron density can be obtained by measures the round trip delays of transmitting microwave beams that are reflected at specific plasma cut-offs. One of the principal objective of optimized stellarator Wendelstein 7-X (W7-X) is to demonstrate the confinement of fast ions at finite plasma beta[1]. For the generation of fast particles an ion cyclotron resonance heating (ICRH) system is designed and implemented at W7-X [2]. For the coupling of the heating power into the plasma it is essential to know the density profile in front of the ICRH antenna. Therefore a density profile reflectometer is designed and installed in the ICRH antenna setup. The ICRH module as well as the density profile reflectometer have commissioned in the recent campaign (OP2.1, until end of Mar. 2023).

The reflectometer electronics utilize a frequency modulated continuous wave (FMCW) scheme with a heterodyne detection method to achieve a sub-millisecond $\mathrm{n_e}$ profile measurement. It consists of two sub-systems including the one at E-band (60 GHz - 90 GHz) and another at W-band (75 GHz - 110 GHz). The minimum probing frequency for E-band system is 67.2 GHz which is decided by the initial frequency of Voltage controlled Oscillator (VCO). The reflectometer polarized in extraordinary mode (X-mode), corresponding to a measurable upper cut-offs density of $\mathrm{n_e} \leq 6 \times 10^{19}\ \mathrm{m^{-3}}$ at the central magnetic field of $\mathrm{B_0} = 2.5\ \mathrm{T}$. While the capability of measurement can be extend if the lower X-mode cutoffs is observed. The detail description of the electronic diagram can be seen in [3, 4].

Localization of the reflectometer and its layout

Due to an intrinsic 3D structured magnetic topology for W7-X, the density measurement from multiple sight lines would be preferable to reveal the non-symmetry nature of profiles in particular around island structures in the plasma edge and outside the separatrix. Therefore two poloidally separated antenna pairs are mounted on the ICRH antenna to enable simultaneous measurement through different view of plasma boundary, as shown in fig 1. The left figure shows the Poincare plot at a toroidal angle of $12.8°$ (ICRH antenna module, AEE31) in the standard magnetic configuration, two red arrows present the Line of Sight (LoS) of two sub-systems. The upper one is the W-band system which LoS passes through the O-point of the magnetic island. While the lower one is the E-band system which the LoS passes through the X-point of magnetic island. The reflectometer is installed on the platform of ICRH antenna (configured with two straps) as dispatched in the right figure. Two pairs of transmission lines (TL) are assigned for the system. The TL consists of an oversized wave-guide in Ka-band (WR28) inside the vacuum, which

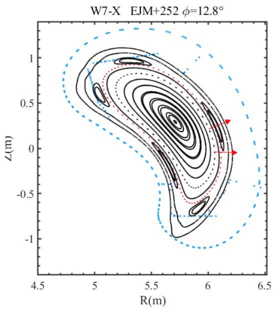

Figure. 1: Overview of diagnostic set up. Left figure shows the Poincare plot at toroidal angle of 12.8° the module AEE31, red arrows indicate light of sight for two subsystems respectively. Right figure shows the reflectometer layout emphasized by color, the ICRH transmission line id depicted in grey. The sectoral horn structure, vacuum window and electronic box of reflectometer is shown in detail in the individual figure.

shares the pipe for the electrical cables. Leaving the supporting pipe, the transition between the vacuum and the air is sandwiched with a 0.1 thick Mica window. Outside this window the wave guide is tapered to the fundamental wave-guide (E-band/ W-band) and connected to the reflectometer. In order to avoid any conflict with the ICRH system, the routing of the wave-guide in the vacuum has to be bent by four times. To minimize the excitation of higher order modes in the wave-guide and hence to reduce the transmission loss, the bends have been manufactured in the hyperbolic shape with an increasing curvature to decrease mode conversion. The electronic box of reflectometer is located on top of the sliding carrier of the ICRH system. The total length for single path of the TL is 4.7 m/path in the upper branch and 4.1 m/path in the lower one. Two sectoral horn pairs have been designed to meet the requirements of the ICRH antenna setup. The locations of these antenna pairs are determined based on space availability within the ICRH antenna and the need to measure density profiles at specific positions of interest for the ICRH. The geometry of sectoral horns are customized in order to make sure the main lobe of microwave beam penetrate outside the ICRH straps and to minimum the side lube reflection as well.

Figure. 2: System performance during the ICRH antenna trolley moving, (a)-(c) beat frequency f_{beat} variation and (d) the distance difference comparison between the result deduced from reflectometer measurement and the ICRH antenna trolley moving.