Measurement of Single Pass Electron Cyclotron (EC) Absorption Using Transmitted Waves in Heliotron J

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Single pass absorption of second-harmonic EC waves propagating obliquely to the magnetic field has been studied in Heliotron J. Two orthogonal signals of transmitted high power EC waves are measured to estimate the single pass absorption rate. The experimental results agree well with ray tracing calculation results based on a linear absorption theory under the condition that the refraction effect is not strong, $n_e/n_c < 0.3$ (n_c is a cut-off density of second-harmonic X-mode), that is, the waves reach the diagnostic port.

Keywords: electron cyclotron absorption, microwave transmission, oblique propagation, absorption efficiency, wave polarization, Heliotron J

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Precise knowledge of propagation and absorption of electron cyclotron waves is important for transport studies and plasma investigations. There are three major methods of measuring the power absorption, (a) the time response of total stored plasma energy to a modulation of the heating power, (b) the time response of electron density and temperature profiles, and (c) direct measurement of power by using pick-up microwave horns opposite to the launcher. Although the second scheme yields the power deposition profile and the total absorbed power, it is a little hard task to apply it to many plasma shots. On the other hand, measurement of the integrated absorption can be made by detecting wave signals which propagate across the plasma from the antenna. Since this method is much simpler than the heat transport analysis, it is useful for monitoring the power absorption.

In this paper, we present experimental results on the single pass absorption of second harmonic X-mode by measuring transmitted waves in Heliotron J. A simple diagnostic system has been developed for estimating the single pass EC power absorption rate. The dependence on the polarization of injected waves is described, comparing with a ray tracing calculation.

Heliotron J is a helical-axis heliotron device aiming at developing quasi-isodynamic configurations with a continuous helical winding as a new heliotron concept [1]. Plasmas are routinely produced and heated by using a 70 GHz 400 kW ECH system at $B = 1.25$ T [2, 3], corresponding to second-harmonic X-mode heating. As illustrated in Fig. 1, a non-focused Gaussian beam is injected from the top of the torus at the straight section where the B contour has a saddle type shape. Although the beam is injected perpen-

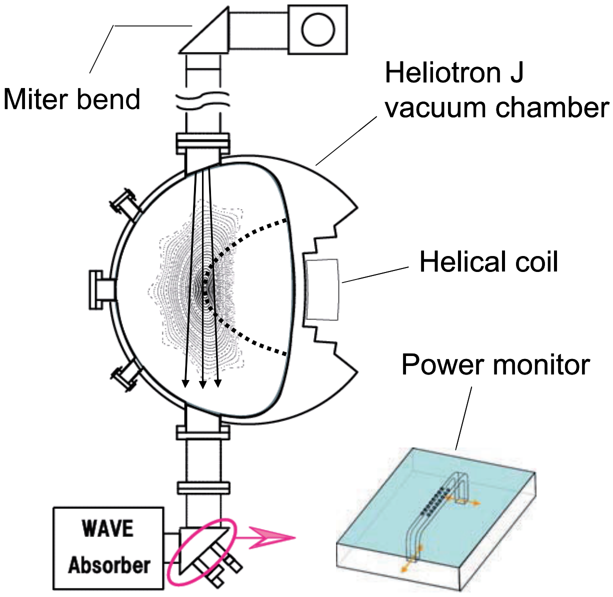

Fig. 1 Schematic view of transmitted wave detection system in Heliotron J. The dotted line denotes the second harmonic cyclotron resonance, $\omega_0/\omega = 0.5$. Here ω_0 and ω are the electron cyclotron frequency at magnetic axis and the wave frequency, respectively.

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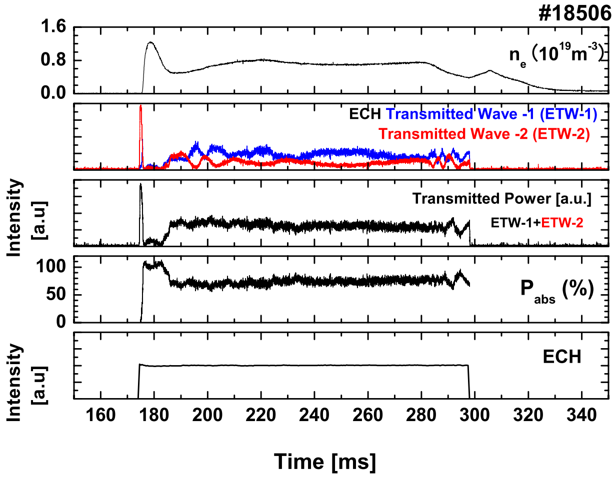

Fig. 2 Time evolution of transmitted waves in ECH plasma on Heliotron J. The plasma is produced and sustained by ECH. The signals denote the electron density, measured transmitted wave intensities, summation of transmitted wave intensities, estimated absorption efficiency, and injected ECH power.

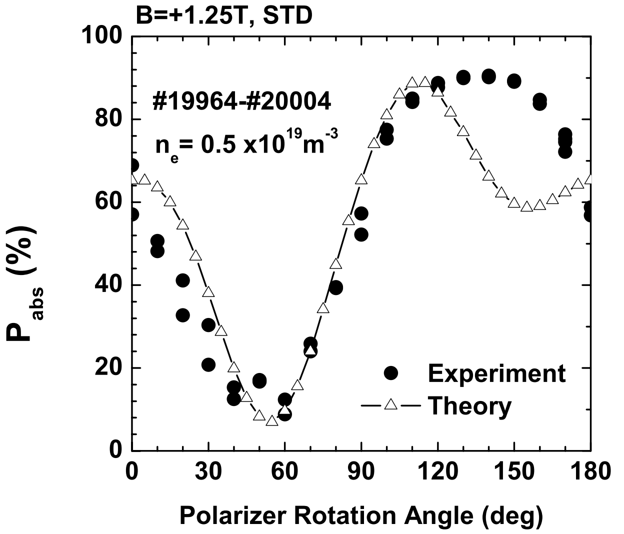

Fig. 3 Dependence of single pass EC absorption efficiency on polarizer rotation angle. The open triangle symbol denotes the ray tracing calculation results.

dicularly with respect to the equatorial plane, the parallel refractive index is finite along the transmission path due to the 3D structure of Heliotron J plasma. The angle between the wave vector and the magnetic field at the magnetic axis, for example, is $\theta = 64$ deg in vacuum, corresponding to the parallel refractive index of $N_{\|} = 0.44$. The polarization of injected waves is controlled by a polarizer assembled on a miter bend in the HE_{11} mode transmission line [4]. A power monitor with two multi-hole arrays, which works as directional couplers, is installed on the miter bend, detecting two orthogonal polarized waves transmitting through plasmas simultaneously. Dial-controlled attenuators are inserted to calibrate two transmitted wave signals.

An example of the time evolution of ECH plasma is shown in Fig. 2. The magnetic field configuration is chosen to be "standard configuration." The injected waves consist of 90 % of the X-mode and 10 % of the O-mode. Before plasma production, the waves propagate as electromagnetic waves in vacuum. We confirmed that the polarization of forward waves agreed with that expected from the launched polarization, indicating that the system detects the wave polarization correctly. While each detector signal oscillates in time depending on the electron density, the summation of the detector signals is kept almost constant, giving the total single pass absorption rate and its time evolution. The total single pass absorption rate including both modes is estimated to be 80 % at $n_e = 0.5 \times 10^{19}\mathrm{m}^{-3}$ and $T_e = 500\,\mathrm{eV}$. The signal intensity is detected without any averaging procedure, resulting that the time evolution of the absorption can be traced during the discharge.

A density scanning experiment has been performed in order to determine the applicable density regime for this measurement scheme. The measurement results are compared with numerical calculation results obtained by a ray tracing code, "TRECE," which was originally developed for TJ-II and applied to Heliotron J [5]. In this code, the 3D magnetic field configuration of Heliotron J plasma is accurately considered. The measured single pass absorption rate of about 90 % for the second harmonic X-mode is consistent with the ray tracing results at $n_e < 0.8\times10^{19}\mathrm{m}^{-3}$, but it gradually increases with increasing density, while the calculated rate decreases at high density. The decrease in the calculated absorption rate is due to the refraction effect by which some fraction of rays does not cross the saddle-type resonance layer (see Fig. 1). In the experiment, on the other hand, the single pass absorption is overestimated at high density since the waves do not reach the diagnostic port due to the refraction. The upper density limit for reliable measurement in 70 GHz second-harmonic X-mode ECH on Heliotron J is $n_e/n_c \sim 0.3$ corresponding to $\omega_{pe}/\omega \sim 0.36$. Here ω_{pe} is the plasma frequency.

Figure 3 shows the dependence of single pass absorption rate on the polarizer rotation angle. The electron density is fixed as $n_e = 0.4\text{-}0.5 \times 10^{19}\mathrm{m}^{-3}$. The polarization of injected waves is widely scanned from the X-mode to the O-mode by rotating a polarizer assembled in a miter bend of the HE_{11} transmission line. The measured total single pass absorption efficiency is in good agreement with the TRECE results. The same tendency is observed when the direction of confinement magnetic field is reversed. The deviation at around 150 deg will be investigated in the future.

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