

## Ray Tracing Calculation of ECRH Power Absorption for Heliotron J

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A ray tracing code, TRECE, of electron cyclotron resonance heating (ECRH) has been developed for the helical-axis heliotron, Heliotron J. The accurate power absorption profile can be obtained for the three dimensional structure of flux surfaces and magnetic field in Heliotron J. The calculation shows that the launching condition of the 70 GHz ECRH system assures a well localized power deposition.

**Keywords:** ray tracing, ECRH power absorption, TRECE code, neural network, Heliotron J

Electron cyclotron resonance heating (ECRH) is widely used in many magnetic confinement devices. Especially in helical devices, current-free plasmas are routinely produced by this heating method. Heliotron J, a helical-axis heliotron device, has the three-dimensional magnetic field structure and the spatial magnetic axis [1]. Due to its complex shape, a wide range of injection angle and polarization mode with precise control is required to achieve the efficient single pass absorption. We have introduced a 70 GHz ECRH system for the purpose of localized heating and improving the accessible density, which makes it possible to perform various experiments such as plasma profile control and electron cyclotron current drive [2]. The 70 GHz ECRH system injects a focused Gaussian beam into the vacuum vessel of Heliotron J with 22 mm beam waist (the plasma minor radius is 140 mm). Due to the steering capability of the injection system, 0° to 30° and 26° to -11° in the toroidal and poloidal directions, respectively, it is possible to explore on- and off- axis heating over most of the plasma radius ( $0 < r/a < 0.7$  where  $r$  is the averaged plasma minor radius and  $a$  is the averaged minor radius of the last closed flux surface). The available injection power to the vacuum vessel is up to 0.4 MW.

To evaluate the ECRH single pass absorption under

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real experimental conditions, ray tracing simulations have been performed with the TRECE code. TRECE is a three-dimensional ray tracing code capable of computing the electron cyclotron absorption and the electron cyclotron emission [3,4]. The TRECE code was originally developed for the TJ-II device at CIEMAT, and it has been modified and applied to the Heliotron J configuration. The code solves the radiative transfer equation in geometrical optics approximation, and computes the absorption and emission coefficients using a weakly relativistic approximation for the Hermitian part of the dielectric tensor, and the fully relativistic expressions for the anti-Hermitian part of the dielectric and microscopic current correlation tensor, retaining all Larmor radius effects. A set of differential equations defining the ray trajectory is solved in the Cartesian coordinates by using Runge-Kutta method.

To calculate the absorption and emission coefficients along the ray path, the local density, temperature and magnetic field strength are needed. The magnetic field is usually available in real space, but the density and temperature are "flux" quantities, which are much better described in flux co-ordinates, especially in fully three-dimensional plasmas. As a result, the problem of finding a transformation between real space and flux co-ordinates has to be solved. The approach

used in TRECE consists in defining a real-to-flux coordinate transformation based on a neural network.

The transformation using a neural network is very quick and relatively accurate (0.1% on average), but even a small error around the magnetic axis would be unacceptable (an error of  $10^{-3}$  translates, for a plasma of 20 cm radius, in an error of approximately 0.6 cm). Since a direct transformation from real space to flux coordinates is much more time consuming, a two-step method has been developed. First the flux estimation from the neural net is obtained, if the flux is larger than a given threshold (meaning that the relative error is small) the value is returned; but closer to the axis (where the flux is smaller), the neural network estimate is used as a first guess to solve numerically the inverse transformation. Thus, high accuracy is guaranteed everywhere.

Calculations are presented using the actual magnetic field of Heliotron J. The magnetic field, created by a helical coil, three types of poloidal coils and two types of toroidal coils, is stored in the three-dimensional grids. The total magnetic field for any configurations is obtained by linear combinations of the different sets of coils with its actual currents. In this study, a reference configuration, namely “standard configuration” has been used for these simulations. The wave frequency is 70 GHz and the heating mode is the second harmonic X-mode corresponding to the resonance magnetic field of 1.25 T.

Figure 1 shows an example of ray trajectories (145 rays are used). A poloidal projection at the toroidal injection angle,  $\varphi = 11^\circ$ , is plotted. The parallel beam is launched at  $z = 70$  mm from the equatorial plane, and its radius is assumed to be 20 mm. The rays are launched with a small toroidal injection angle to check the three dimensional effect. The injection position is the same as that of the experimental condition. The electron temperature and density profiles are assumed to be nearly parabolic and broad, and their central values are set 0.3 keV and  $2.0 \times 10^{19} \text{ m}^{-3}$ . For this value of the resonant magnetic field, the absorption takes place a little off-axis. It is clear to see the refraction of the beam at the top view. Under this condition, it is found that the single pass absorption is 69% and the power absorption profile is localized at  $0.1 < r/a < 0.2$  as shown in Fig.2.

In summary, the TRECE ray tracing code has been developed and successfully applied to Heliotron J, including its fully three-dimensional geometry and ECRH launching conditions. The code is flexible enough to include easily various plasma profiles and

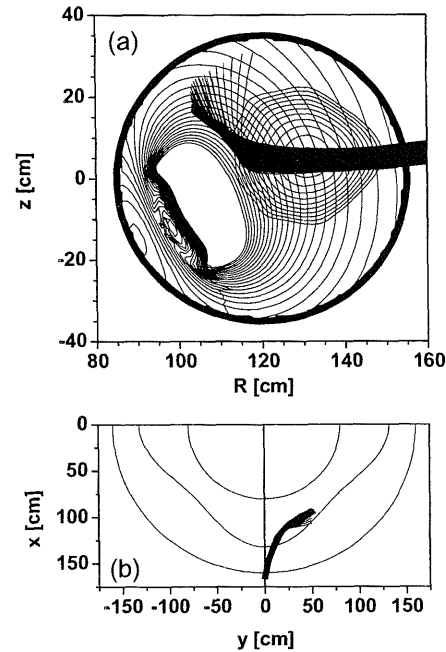


Fig. 1 Ray trajectories in a Heliotron J plasma, (a) poloidal projection and (b) toroidal projection. The parameters are  $f = 70$  GHz,  $B = 1.25$  T and  $\varphi = 11^\circ$ .

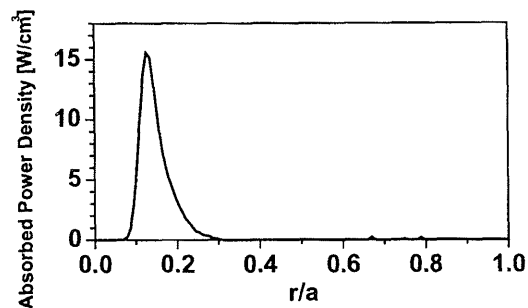


Fig. 2 Power absorption profile. The total injected power is 0.38 MW. The input parameters are the same as in Fig. 1.

launching directions.

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