§7. Evaluation of Transmission-Line Components Based on Direct Phase Measurements in mm-Wave Frequencies

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Electron Cyclotron Heating (ECH) using high power millimeter waves is an attractive method for plasma production, auxiliary heating, and current drive in a nuclear fusion research. An output beam from a high power gyrotron oscillator is coupled into oversized circular corrugated waveguides in the ECH system, which is transmitted to the launcher using the HE_{11} mode of the waveguide. In order to to analyze the mode content in the waveguide, a new approach is proposed for the low power experiments where precise direct phase measurements are available [1]. The mode content of the waveguide modes was evaluated using the irradiant waveguide modes in the radiated field. In this method, the phase retrieval process was not required.

The field radiated from the waveguide was used to analyze the mode contents transmitted in the waveguide. The radiated fields were calculated by the Kirchhoff Integral in the paraxial approximation. The irradiant waveguide modes Φ_{mn} which are the radiated waveguide eigen modes ϕ_{mn} at the z position were expressed as

$$\Phi_{mn}(x,y) = \frac{ik}{2\pi z}\int \mathrm{d}x'\mathrm{d}y'\phi_{mn}(x',y') \times \exp\Big[\frac{-ik[(x'-x)^2+(y'-y)^2]}{2z}\Big],$$

where the coordinates of (x', y') and (x, y, z) were at the waveguide aperture and at the radiated positions, respectively. The orthogonality of the propagating modes in a free space comes from the parabolic equation. Since the irradiant waveguide modes $\Phi_{mn}(x, y)$ meet the parabolic equation, the functions Φ_{mn} were othogonal bases in the free-space propagation within the paraxial approximation. The mode content p of the (m,n) mode was here described as

$$p = \Big|\int E\Phi^*_{mn}\mathrm{d}x\mathrm{d}y\Big|^2 \Big/ \Big(\int |\Phi_{mn}|^2\mathrm{d}x\mathrm{d}y \cdot \int |E|^2\mathrm{d}x\mathrm{d}y\Big).$$

A Gaussian beam was prepared to inject to a 1m long corrugated waveguide with a diameter of 88.9mm. This injected beam was tilted by 1 degree with respect to the waveguide z axis in the x direction. The electric field was in y direction, in perpendicular to the tilted $x - z$ plane. Here, the wave frequency of the beam was 84 GHz. The distorted intensity profiles were measured at the several propagation position along the z axis. The phase profiles were also measured, and retrieved from the measured intensity profiles by the iteration method. The mode content of the main HE_{11} mode, coupled from the incident tilted Gaussian beam, was 0.72. The remains were the unwanted higher modes. The HE_{21} mode content was 0.13, and the HE_{12} mode was 0.12. The HE_{22} mode and the other higher modes were also excited by the tilted injection.

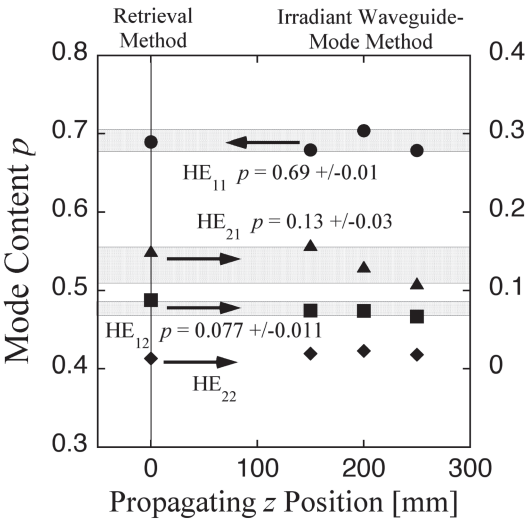

Fig. 1: Mode content p of the HE_{11}, HE_{21}, HE_{12} and HE_{22} modes with the retrieval method (at z=0 mm), and with the irradiant waveguide mode method (at z=150/200/250 mm)

The irradiant waveguide modes $\Phi_{mn}(x, y)$ were calculated for the HE_{11}, HE_{21}, HE_{12} and HE_{22} modes at $z = 150/200/250$ mm by the Kirchhoff Integral, and the mode content was analyzed using the irradiant waveguide modes. Figure 1 shows the analyzed mode content along the propagation direction. The mode content was also evaluated from the retrieved phase and intensity profies. The mode content with the irradiant waveguide modes was in good agreement with that of the retrieval method applied at the output waveguide aperture ($z = 0$ mm). The mode content analyzed with irradiant waveguide modes did not depend on the propagating direction well. In principle, it was independent on the propagating directionin the analysis. Only one field measurement was enough to analyze the mode content transmitted in the waveguide. The phase retrieval process was not required in this approach. In order to avoid some power leakage from the measuring area of the propagating beam, the rather near field or large area measurement was required.

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[1] Idei,H., *et al.*, Proc .of the 32nd Int. Conf. on Infrared and mm-Waves, 69 (2007).