§5. Coupling of Tilting Gaussian Beam with Hybrid Mode in the Corrugated Waveguide

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By using parameters of transmission line system in electron cyclotron heating (ECH) for the LHD, we have examined the coupling efficiency of a gaussian beam with hybrid modes in the corrugated waveguide from the viewpoint of tilting and offset of beam axis.

The calculation is electromagnetic field of tiling gaussian beam and hybrid mode on the entrance of the corrugated waveguide. With the aid of an orthonormal relation between hybrid modes, the coupling coefficient A_j is calculated from

$$A_j = \iint_S (\mathbf{E}_j \times \mathbf{H}^*)^* \cdot d\mathbf{S}, \quad (1)$$

where, $\mathbf{H}$ is the EM field of the gaussian beam at the entrance, and $\mathbf{E}_j$ is hybrid mode, and $\mathbf{S}$ is the whole plane of a cross-section. By rotating the cartesian coordinate (x, y, z) by α and β around x - and y -axes, we can obtain new coordinate (x', y', z') . Thus coefficient A_j is straightforward calculated as

$$A_j = - \iint E_{jy}^* H'_x \cos \beta dx dy. \quad (2)$$

At the same time, the normalized flux of gaussian beam to the waveguide is calculated by

$$P_{WG} = \iint (|\mathbf{E}_y|^2 / Z_0) \cos \alpha \cos \beta dx dy. \quad (3)$$

In Fig. 1, P_{WG} and most of higher modes are plotted as a function of α . To suppress the total higher mode content upto the value of 1%, the tilting angle should be less than 0.1 deg for $\omega/2\pi=168$ GHz and $2a=88.9$ mm.

The contours $|A_{HE11}|^2$ for $w_0/a=0.6435$ are calculated in the $(1/2a, \alpha)$ plane as a parameter of $|A_{HE11}|^2$. All the contour curves which are straight line pass the origin $(0, 0)$. In the approximation of $\tan \alpha \simeq \alpha$, α is inversely proportional to a for constant $|A_{HE11}|^2$, and it is found that $|A_{HE11}|^2$ depends on the product of $a\theta$ by

taking into account axisymmetry of $|A_{HE11}|^2$. Here, $\theta = \sqrt{(\alpha^2 + \beta^2)}$.

In Fig. 2, contours are also plotted as a parameter of the incident angle for $|A_{HE11}|^2=0.970$ at $w_0/a=0.6435$. All the lines pass through the origin $(0, 0)$. In the ECH system of the LHD, if the injection angle can be adjusted so as to satisfy $\alpha < 0.1$ deg, $|A_{HE11}|^2 > 0.97$ is achieved. It is found that $|A_{HE11}|^2$ depends on a/λ . As a result, it becomes evident that $|A_{HE11}|^2$ is a function of $a\theta/\lambda$. In order to obtain the scaling formula, fitting of $|A_{HE11}|^2$ in Fig. 1 is carried out and after some substitution, we obtain:

$$|A_{HE11}|^2 \simeq 0.98 - 3.9(a\theta/\lambda)^2 + 3.4(a\theta/\lambda)^4. \quad (4)$$

Here, the unit of θ is radian.

Fig. 1. P_{WG} and $|A_{HE11}|^2$ as a function of α .

Fig. 2. Contour plots of α in the $(\lambda, 2a)$ plane for satisfying $|A_{HE11}|^2=0.970$ when a gaussian beam with $w_0/a=0.6435$ is injected with $\beta=0$.