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Design of a steerable launcher for the ECH system on KSTAR

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Abstract. 105/140Ghz dual frequency gyrotron is used in KSTAR tokamak for an electron cyclotron resonance heating (ECRH). The ECH launcher consists of a fixed mirror, a steering mirror, cooling systems and some mechanical component for a steering mirror. We have designed the fixed ellipsoidal focusing mirror for an efficient heating and localized control. The beam radius using the existing ECH launcher system is about 45 mm at the resonance layer. On the other hand, the modified launcher mirror reduces the beam size at the resonance layer for incident RF beam to 38 mm. The design results showed good agreement compared with the computation and simulation results. Since the distance between the corrugated waveguide and the fixed focusing mirror is fixed, it is difficult to more reduce the beam size. However, reduced beam size is small enough to localize MHD control and heating.

1 Introduction

A gyrotron is a high powered linear beam vacuum tube and has emerged as an excellent radio frequency (RF) source, which is commonly used for plasma heating, current drive of fusion devices, dynamic nuclear polarization (DNP), nuclear magnetic resonance (NMR), and so on [21-25]. Electron cyclotron heating (ECH) and electron cyclotron current drive (ECCD) launcher system has installed on the KSTAR tokamak. An ECH/ECCD system is required for localized plasma heating, plasma startup for large superconducting tokamak device, pre-ionization for low voltage startup, non-inductive current drive, and discharge cleaning of a vacuum vessel [1-3]. Recently, ECH/ECCD system is used in MHD instability modes control such as suppression of neoclassical tearing mode (NTM), control of sawtooth and internal transport barriers for high-performance and stability of the plasma [4-6]. One of advantage of ECH/ECCD system is localizing the deposited power. In order to increase efficient plasma heating and localized absorption of the RF power, we modified a flat fixed mirror to an elliptical mirror and designed the elliptical mirror.

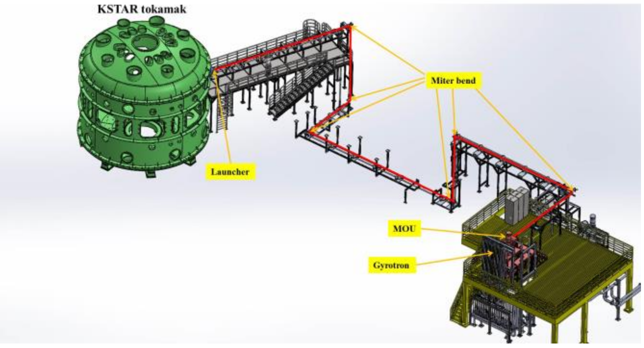

Fig. 1 Schematic of the ECH system with transmission line(red line) on KSTAR

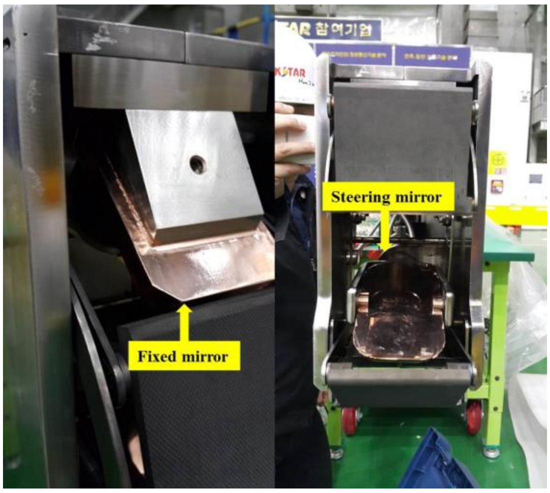

Fig. 2 Fixed mirror and steering mirror of ECH launcher for KSTAR

2 Launcher for KSTAR ECH system

Electron cyclotron heating (ECH) and electron cyclotron current drive (ECCD) launcher system has installed on the KSTAR tokamak to inject the high power, high frequency RF beam from transmission line system. 1MW/300s/105/140Ghz dual frequency gyrotron is used in KSTAR tokamak for an electron cyclotron resonance heating (ECRH).

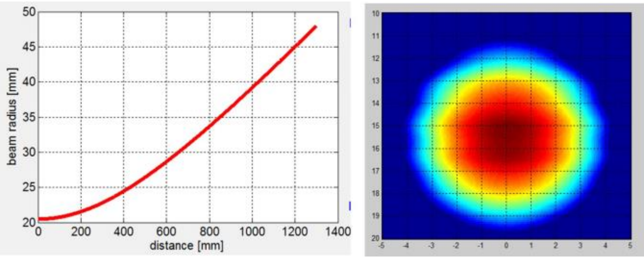

Fig. 3 Calculation (left side) and simulation result (right side) of ECH launcher using both of flat mirror

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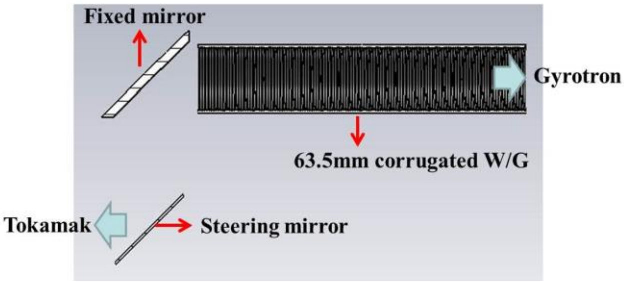

Fig. 4 Drawing of the ECH launcher system for simulation

The gyrotron system is connected to transmission line system. A transmission line system of ECH system of KSTAR tokamak consist of several miter bend (M/B), a matching optic unit (MOU) and a hundred meters of evacuated corrugated waveguide (W/G) as shown in Fig.1. The high power, high frequency RF beam generated by the Gyrotron is transmitted by the HE11 corrugated waveguide to the launcher. The corrugated waveguide radiates the Gaussian-like RF beam with its beam waist situated at the waveguide output. Radiated RF beam from corrugated waveguide spreads quickly in free space and the beam is reflected by two mirrors. Fig.2 shows the ECH launcher of KSTAR. Both of two mirrors of the launcher has flat surface. KSTAR is a medium size tokamak with a major radius of 1.8 m and a minor radius of 0.5 m. The distance of the resonance layer from the launcher is about 1 m. Fig.3 shows the calculation result using the quasi-optical Gaussian theory and simulation result, respecprively. The beam radius is about 45 mm at the resonance layer because of two flat mirrors. As shown fig. 4, the distance is about 47mm from the corrugated waveguide to the fixed mirror and the distance is about 156 mm from the fixed mirror to the steering mirror. The traveling distance of the reflected beam by the steering mirror is about 1000 mm. In order to increase efficient plasma heating and localized absorption of the RF power, we modified a flat fixed mirror to an elliptical.

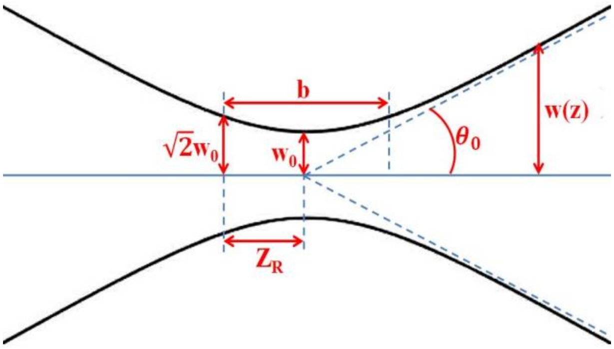

Fig. 5 Gaussian beam width $w(z)$ as a function of the distance z from the axis of propagation with beam waist(w_0), Rayleigh range(z_r), depth of focus (b) and far-field divergence angle (θ_0).

3 Basic principle of mirror design

As mentioned above, output beam of gyroton is transmitted in HE11 mode. Gaussian beams diverge in the axis of propagation direction as shown in Fig. 5, and in the paraxial limit the beam radius as a function of position along the direction is defined as [8, 9] .

$$w(z) = w_0\sqrt{\left[1+\left(\frac{\lambda z}{\pi w_0^2}\right)^2\right]} \tag{1}$$

where, w_0 is the beam waist radius. In Eq. (1), the quantity $\frac{\pi w_0^2}{\lambda}$ is called the confocal distance (z_c) or Rayleigh range(distance from the beam waist on the axis of the propagation where the beam radius is increased by a factor of $\sqrt{2}$). From the axis of propagation, the power density $P(r,z)$ of the Gaussian beam is given by [10].

$$P(r,z) = P_0(z)\exp\left[-2\left(\frac{r}{w(z)}\right)^2\right]. \tag{2}$$

Here, P_0 is the maximum power density at $r=0$ and $w(z)$ is the beam radius. The total power is proportional to the power integrated over the area of the beam passing any perpendicular plane on the axis of the propagation.

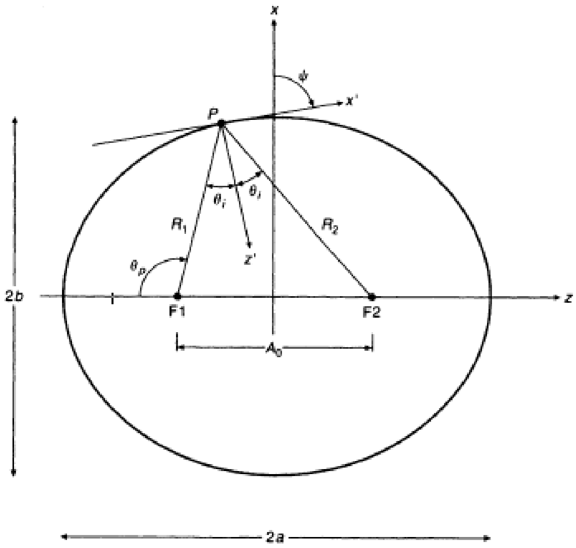

Fig. 6 Geometry of ellipsoidal reflector. F1 and F2 are the focal points of the ellipse, and R1 and R2 are the distances from the point P on the surface to the focal points [7].

The total power is irrelevant to the axis of the propagation in lossless space and expressed as

$$\begin{aligned} P_{rad} &= \frac{1}{2} P_0(z) \pi w^2(z) \\ P_0(z) &= \frac{2P_{rad}}{\pi w^2(z)}. \end{aligned} \tag{3}$$

Substituting Eq. (3) into Eq. (2), the power density of the Gaussian beam can be written as

$$P(r,z) = \frac{2P_{rad}}{\pi w^2(z)} \exp\left[-2\left(\frac{r}{w(z)}\right)^2\right]. \tag{4}$$

The Gaussian-like beam radiated by corrugated waveguide is converged by the focusing mirror. In order to focus the incident beam with some angle, the focusing mirror should be ellipsoidal surface. The ellipsoidal model is rotationally symmetric about its major axis, which as shown in Fig.6. The equation of the ellipsoid surface is :

$$\begin{aligned} &\frac{y^2}{b^2} + \frac{\left[x^2 + z^2 + 2z(R - h_0)\right]}{a^2} = 1 \\ &b = \frac{a}{\cos\theta}, h_0 = R - \sqrt{R^2 - a^2}, r = 2F\cos\theta \end{aligned} \tag{5}$$

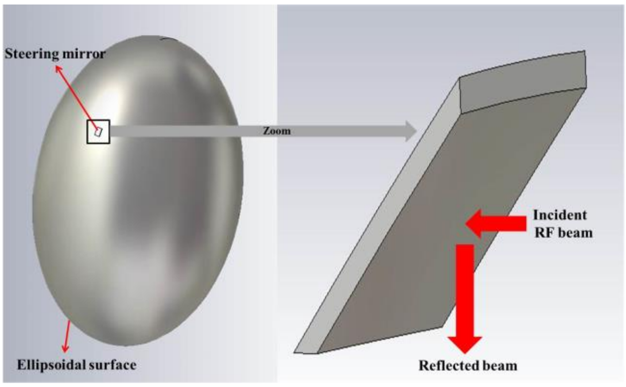

Fig. 7 Ellipsoidal surface and a part of the ellipsoidal surface (focusing mirror)

4 Result and conclusion

A new quasi-optical launcher has been modified and designed for KSTAR ECH system.

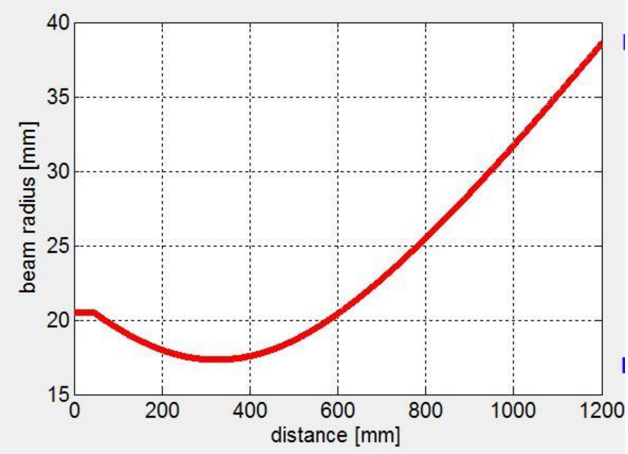

Fig. 8 Beam radius along the propagation trajectory

Fig.7 shows the new designed fixed mirror for ECH launcher system. The beam radius along the propagation path is shown in Fig. 8. As shown in this result, the focusing mirror is located at 47 mm away from the corrugated waveguide output and the beam radius is about 38 mm at the resonance layer (about 1200mm). Fig. 8 shows that the beam size is smaller at the resonant layer compared to the reults in Fig. 3. Fig. 9 is the Surf 3D code result which is commercial code and shows the beam path trajectory result from the waveguide output to the resonance layer. In this result, the beam radius is also about 39 mm at the resonance layer. This result also shows that the beam size is reduced at the resonant layer compared to the reults in Fig. 3. It is small enough to localize MHD control and heating. Actually, the beam size can be further reduced by using a focusing mirror and it is one of ways to use ECH more effectively. However, since the distance between the corrugated waveguide and the fixed focusing mirror is fixed, it is difficult to more reduce the beam size. In order to more reduce the beam size at the resonant layer, the structure of the launcher have to changed. Since changing the structure of the launcher is out of scope of this research, it will be deal with in the future research.

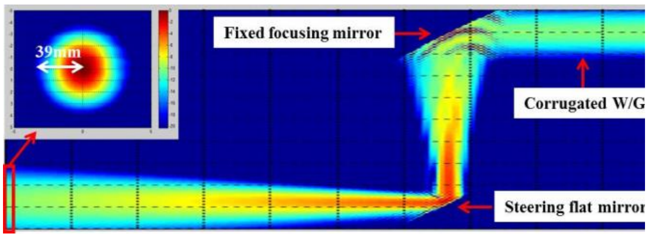

Fig. 9 Simulation result of a Gaussian-like beam reflection in an ellipsoidal fixed mirror and flat steering mirror

References

1. C. H. Liu, D.H. Xia, D.L. Sun, Z.J. Wang, J.X. Xiao, Z. Zeng, F.T. Cui, Z.X. Yu, G. Zhuang,

"Design of a polarization-controlled launcher for the ECH system onJ-TEXTC," Fusion Eng.Des. 112 (2016) 404–409.

2. R. Prater, "Heating and current drive by electron cyclotron waves," Phys.Plasmas 11 (2004) 2349–2376.
3. S. Gnesin, J. Decker, S. Coda, T.P. Goodman, Y. Peysson, D. Mazon "3rd harmonic electron cyclotron resonant heating absorption enhancement by2nd harmonic heating at the same frequency in a tokamak," Plasma Phys.Control. Fusion 54 (2012) 035002
4. N. Kobayashi, G. Bosia and B. Petzold "Design status of EC system in ITER — design of reliable RF beam launching system," Fusion Eng.Des. 53 (2001) 475–484
5. T. Shimozuma, H. Igami, S. Kubo, Y. Yoshimura, H. Takahashi, M. Osakabe,et al., "Optimization of the high harmonic ECRH scenario to extend a heatingplasma parameter range in LHD," Nucl. Fusion 55 (2015) 063035
6. T. Omoria, M.A. Henderson, F. Albajar, S. Albertic, U. Baruahd, T.S. Bigelowe,et al., "Overview of the ITER EC H&CD system and its capabilities," Fusion Eng.Des. 86 (2011) 951–954
7. P. F. Goldsmith, "Quasioptical system," Chap.5
8. S. G. Kim, A. Sawant, I. Lee, D. Kim, M. S. Choe, J. H. Won, J. H. Kim, J. So, W. J, and E. M. Choi, "System development and performance testing of a W-band Gyrotron," J. Infrared Milli. Terahz. Waves, vol. 14, pp. 1-14, 2015
9. S. G. Kim, J. H. Kim, J. H. Won, W. Lee, J. Y, and E. M. Choi, "Direct real-time power measurement of a high-power electron cyclotron maser by a simple one-point Schottky detector signal," IEEE Trans. THz Sci. Technol., vol. 5, pp. 779-785, 2015
10. M. E. Read, G. S. Nusinovich, O. Dumbrajs, H. Q. Dinh, D. Opie, G. Bird, K. Kreischer and M. Blank, "Design of a 3 MW, 140 GHz, gyrotron based on a $TE_{21,13}$ coaxial cavity," *in Proc. 18th Int. Cont. Infr. Millim. Waves,* vol. SPIE 2 104, p. 521, 1993