Experimental Study on Collimation Characteristics of an ECRH System with a 28GHz/50kW Gyrotron

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Abstract. In this paper, the collimation characteristics of an electron cyclotron resonance heating (ECRH) system with a 28GHz/50kW gyrotron in EXL-50 are studied experimentally. Through using laser trackers and designing matching tooling, test errors of horizontal distances and vertical distances between the transmission line and the flange center are all within 1mm, which are less than 0.4% and 0.07% respectively. In addition, online beam spot test with a 150 ms short pulse from a 28 GHz gyrotron also proves good collimation characteristics of the ECRH system. Finally, spherical plasma is formed through injecting the microwave to the vacuum chamber.

1 Introduction

EXL-50 is a medium size spherical Tokamak^[1] without central solenoid, whose major $R = 0.58m$ and minor radius are $r = 0.41m$ and respectively. Electron cyclotron Resonance Heating is currently the only method to start and maintain plasmas. Photo of the ECRH system with a 28GHz/50kW gyrotron^{[2]-[4]} in EXL-50 is shown in Figure 1. Figure 2 shows the layout of the ECRH system in EXL-50. The triode magnetron injection gun is used in the 28GHz/50kW gyrotron, which achieved 54.8kW/1s and 45.6kW/30s output power.

Fig. 1. Photo of the ECRH system with a 28GHz/50kW gyrotron in EXL-50

Fig. 2. Layout of the ECRH system in EXL-50

The left and right sides of Figure 1 are the antenna and the microwave source of the ECRH system respectively, and the transmission line is between them. The components of the transmission line include straightener, corrugated waveguide, waveguide switch, quasi-light elbow, and the whole distance is about seven meters.

How to ensure collimated transmission of microwaves in the seven-meters transmission line is very important, because non-collimated transmission will cause strong microwave reflection, which in turn will damage transmission components, gyrotron and so on. Therefore, it is particularly significant to study the collimation characteristics of the ECRH system experimentally.

2 Experimental method and results

For the accuracy of collimation characteristics experiments, FARO Vantage laser tracker^[5] is used, which are extremely accurate, and portable coordinate measuring machines that enable users to build products, optimize processes, and deliver solutions by measuring quickly, simply, and precisely.

A novel matching tooling is designed and machined to cooperate with the use of the laser trackers. Figure 3 (a) is the designed matching tooling with corrugated waveguide, and Figure 3 (b) shows the machined matching tooling with corrugated waveguide and target ball of the laser tracker.

A total of six identical matching toolings have been used in the transmission line of the ECRH system. Five of them are evenly distributed between matching optical unit (MOU) and quasi-light elbow, and the other one is near the antenna.

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Fig. 3. (a) The designed matching tooling with corrugated waveguide. (b) The machined matching tooling with corrugated waveguide and target ball of the laser tracker.

Through adjustment by using a laser tracker, horizontal distances between the transmission line and the flange center at six sampling points are acquired and shown in Table 1 (A). Seen from this table, the test errors are within 1mm, namely less than 0.4%. Similarly, vertical distances between the transmission line and flange center at six sampling points are shown in Table 1 (B). The test errors are also within 1mm, namely less than 0.07%. It is worth explaining that the height difference between the sixth sampling points and the other five ones comes from the height of quasi-light elbow, and the designed value is 300 mm.

Table 1. (A) Horizontal distances between transmission line and flange center (Units: mm)

Element	Value
Sampling Points 1	102.0
Sampling Points 2	102.0
Sampling Points 3	102.6
Sampling Points 4	102.6
Sampling Points 5	102.6
Sampling Points 6	102.3

Table 1. (B) Vertical distances between transmission line and flange center (Units: mm)

Element	Value
Sampling Points 1	380.0
Sampling Points 2	380.0
Sampling Points 3	379.8
Sampling Points 4	380.2
Sampling Points 5	380.3
Sampling Points 6	80.0

To verify the collimation characteristics of the transmission line, the online beam spot test with 28GHz/50kW gyrotron is conducted. The detailed experimental parameters are shown in Table II. The beam spot status can be viewed on thermal papers, which are shown in Figure 4. Figures 4 (a), (b), (c), and (d) are the beam spots at a distance of 200 mm along the corrugated waveguide from MOU, 700 mm from MOU, 1700 mm from MOU and the beam spot after microwave passes through the quasi-light elbow, respectively.

Table 2. The detailed experimental parameters used in beam spot test

Parameters	Value
Cathode voltage	-34kV
Anode voltage	+1kV
Control pole voltage	-6kV
Excitation current	44.3A
Filament current	6.6A

The bright central regions of the four pictures represent the energy concentration areas, and the black regions are low energy areas. Combining Figures 4 (a), (b), (c) and (d), the conclusion could be drawn that the microwave is collimated transmitted, which also proves good collimation characteristics of the ECRH system.

Fig. 4. (a) The beam spot at a distance of 200 mm along the corrugated waveguide from the MOU. (b) The beam spot at a distance of 700 mm along the corrugated waveguide from the MOU. (c) The beam spot at a distance of 1700 mm along the corrugated waveguide from the MOU. (d) The beam spot after microwave passes through the quasi-light elbow.

Fig. 5. The simulated energy distribution of Gaussian beam

Figure 5 is the simulated energy distribution of Gaussian beam. Seen from this figure, the red region is high energy area, and with outward expansion, the energy becomes lower and lower. Compared with figure 5, the photos in figure 4 could be considered as Gaussian beam.

When conducting the online beam spot experiment, the microwave is injected to the water load through waveguide switch. After that, the waveguide switch is switched to the through state so that the microwave is injected to the vacuum chamber. Spherical plasma is formed, which is shown in Figure 6. Figure 6 is the photo of #4263 from a high-speed camera. During the formation of spherical plasma, spark protection is in normal operation and there is no reflected wave detected.

Fig. 6. Photo of #4263 from a high-speed camera.

In order to obtain higher plasma parameters, the ECRH system with 28GHz/400kW gyrotron^{[6]-[13]} is under construction.

3 Conclusion

In conclusion, adjusting the collimation characteristics of the ECRH system by designing matching tooling and using laser trackers is pretty good. The test errors of horizontal distances and vertical distances between the transmission line and the flange center are all within 1mm, which are less than 0.4% and 0.07%, respectively. Through the online beam spot test with 28GHz/50kW gyrotron, the microwave could transfer with good collimation in the transmission line of the ECRH system. In addition, the spherical plasma is obtained after the microwave is injected into the vacuum chamber.

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