Plans for the electron cyclotron heating system on J-TEXT

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Abstract. A new 105 GHz/500 kW/1 s electron cyclotron resonance heating (ECRH) system has been designed and being constructed on J-TEXT Tokamak. This system mainly consists of a microwave source, a transmission line, a launcher and other auxiliary units. Based on corrugated waveguides, the wave from the gyrotron can be efficiently transmitted with HE_{11} mode to the steerable quasi-optical launcher for injection. The transmission efficiency is about 85%, and the injection angle of the wave can be adjusted by the flat mirror of the launcher. Commissioning of this electron cyclotron heating system is scheduled to be done at 2019.

1. Introduction

Electron cyclotron resonance heating (ECRH), recognized as a kind of efficiently auxiliary heating method, has been widely used on many tokamaks and stellarators [1-6]. Also, ECRH is proved to be helpful for current profile control, MHD stability, transport study, etc [7]. To fulfill the requirements of heating power on J-TEXT tokamak, an ECRH system with one 105 GHz/500 kW/1s gyrotron is being built.

The ECRH system under design mainly consists of a high power microwave source, a transmission line based on corrugated waveguide, and a launcher connected to J-TEXT tokamak. The tokamak has a major radius of 1.05m and a minor radius of 0.25~0.29m. The center-line toroidal field for normal discharge is about 2T. Considering the parameters above and requirements of our experiments, a 105GHz/500kW/1s gyrotron has been chosen as the microwave source. A transmission line is constructed based on circular corrugated waveguides to transmit electron cyclotron (EC) waves from gyrotron to the port of the tokamak with HE_{11} mode, which is proved to be an efficient way in reducing the loss of power. The launcher is designed according to the expected poloidal and toroidal injection angles and actual limitation of space.

This paper consists of following parts. The details of microwave source are given in Section 2. Section 3 introduces the design of the transmission line. Section 4 gives the parameters of launcher. Conclusions are shown in Section 5.

2. Microwave source

As the high power microwave source of ECRH system, the gyrotron delivers EC waves of megawatt level power at frequency varied from 28~170 GHz. For ECRH system, operating parameters of the whole system are mainly determined by parameters of the gyrotron. According to the theory of EC wave propagation and absorption in plasma, the frequency of gyrotron f is determined by the toroidal magnetic field B_T, as follows [8]:

$$f = nf_{ce} = \frac{eB_T}{2\pi m_e} \approx 28nB_T GH_Z \qquad (1)$$

Where f_{ce} is the electron cyclotron resonance frequency, e is the electron charge, m_e is the electron mass, and n is the number of the harmonic.

For the J-TEXT tokamak, the maximum toroidal magnetic field is 2.4 T at present [9]. Considering the needs of physics experiment and values, the 105 GHz/500 kW/1 s gyrotron, which is manufactured by GYCOM, has been chosen for J-TEXT tokamak. The parameters of this type gyrotron is shown in Table 1. When the EC wave is injected from the low field side of the J-TEXT port 4, the second harmonic of extraordinary mode (X2) will be absorbed at the toroidal magnetic field of about 1.88 T.

Table 1. Parameters of gyrotron.

Parameters	**Values**
Type	Depressed collector
Frequency	105 GHz
Output power	500 kW
Pulse length	1 s
Main output mode	TEM_{00} mode
Efficiency	45%
Output window	BN window

Table 2. Parameters of power supplies.

Parameters	**Values (max.)**
Cathode voltage	55 kV
Accuracy of cathode voltage	0.3 kV
Beam current	25A
Body voltage	27 kV
Accuracy of body voltage	0.5 kV
Body current	150mA
Voltage stability	1%
Filament voltage	30 V
Filament current	30 A
Ion pump power supply	3~4 kV

For this type 105 GHz/500 kW/1 s gyrotron, the power supplies consist of two high voltage power supplies (cathode and body), a filament power supply (PS), a super conducting magnet (SCM) PS and an ion pump PS. The main parameters and their maximum of these PS are shown in Table 2.

Table 3. Parameters of water cooling.

Cooling	**Pressure**	**Flow**	**Others**
Collector	< 0.5 Mpa	> 5 L/s	Temperature ≤ 25°C Resistance ≥ 1MΩ•cm
Cavity	< 0.5 Mpa	> 0.2 L/s	
Window	< 0.5 Mpa	> 0.3 L/s	
Body	< 0.5 Mpa	> 0.2 L/s	
MOU	< 0.5 Mpa	> 0.3 L/s	

Besides, the gyrotron needs water cooling for its collector, cavity, output window, body and matching optics unit (MOU). The main parameters of the water cooling system are shown in Table 3. The water resistance is not less 1 MΩ•cm, and the inlet temperature of the coolant is near or below 25°C. The maximum inlet temperature is 35°C.

3. Transmission line

A transmission line (TL) is responsible for transmitting the EC waves from gyrotron to launcher. The TL must meet the following requirements: high power capability, low attenuation, low probability of arcing, low difficulty in measuring the power of EC waves.

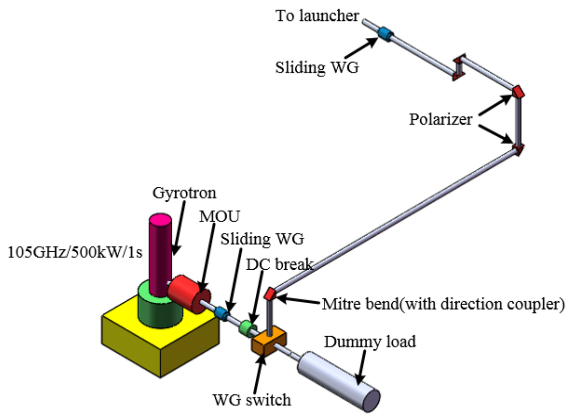

Fig. 1. Layout of a transmission line.

Layout of the TL is shown in Fig. 1 and the composition of the TL is given in Table 4. Since the power is not very high, the transmission line is under atmospheric conditions. The TL is equipped with several corrugated waveguides, two sliding waveguides, a waveguide switch, a DC break, several miter bends, two polarizers integrated into two bends separately, a direction coupler integrated into bend, and a dummy load. The inner diameter of the waveguides which are made of aluminum is 63.5mm, and the sinusoidal corrugations with the period of 1mm and the depth of 0.71mm are adopted. The sliding waveguide is used to compensate the thermal expansion. The DC break cuts off the DC connection between gyrotron and J-TEXT tokamak. With the waveguide switch, the EC waves can be switched to the dummy load for power measurement and calibration by calorimetry [10-11]. The miter bend changes the direction of propagation. The two polarizers work together to get the expected polarization of the EC waves. The direction coupler makes it possible to measure the microwave power online.

Table 4. Compositions of a transmission line.

Component	Quantity
MOU	1
Corrugated waveguides	~24m
Mitre bends	5
Polarizer	2
Direction coupler	1
DC break	1
Waveguide switch	1
Dummy load	1
Sliding waveguide	2

4. Launcher

As shown in Section 3, the EC wave is transmitted to the port 4 (233mm×219mm) on J-TEXT tokamak. A quasi-optical launcher has been designed to inject the beam into plasma with the desired poloidal and toroidal direction. The structure of the designed 105GHz launcher is shown in Fig. 2.

In Fig. 2, the wave is firstly focused by the ellipsoidal mirror, and then it will be reflected to plasma by the steerable flat mirror. The poloidal and toroidal angles of the incident beam can be adjusted with the steerable flat mirror by two separate poloidal and toroidal drivers. The steering mechanism of the flat mirror is shown in Fig. 3. Considering the space limitation of port 4 and the steering mechanism, the poloidal and toroidal rotation angles are ±15°. More details about the design of ellipsoidal mirror and flat mirror can be found in Ref. [12].

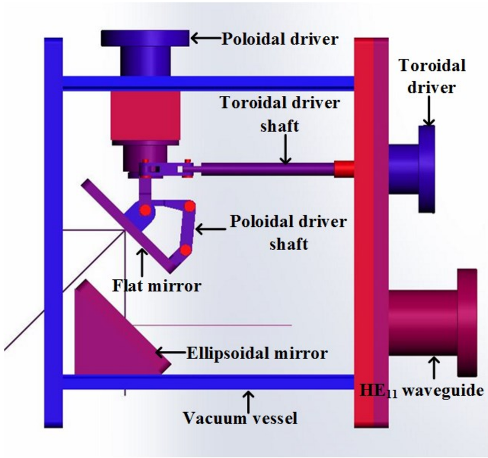

Fig. 2. Structure of the designed 105GHz launcher.

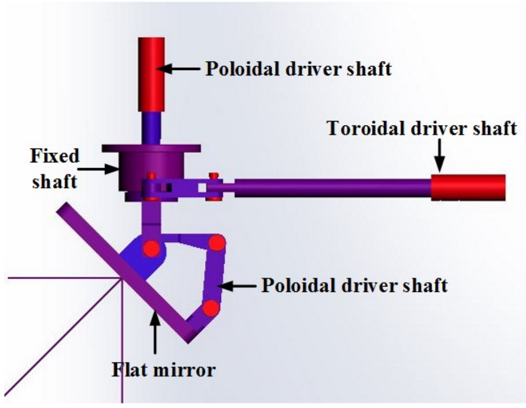

Fig. 3. Steering mechanism of the flat mirror.

Table 5. Parameters of ellipsoidal mirror and flat mirror.

Parameters		Values
Ellipsoidal mirror	F	400 mm
	OA	47 mm
	OB	33 mm
	OE	1.96 mm
Flat mirror	Length	100 mm
	Width	72 mm
	Thickness	10 mm

Considering beam width of the EC wave and space limitation, the calculated parameters of ellipsoidal mirror and flat mirror are given in Table 5, where F is the focal length; OA, OB and OE are the half-length, half-width and depth of the ellipsoidal mirror, respectively. Meanwhile, the length, width and thickness of the flat mirror are abbreviated as L, W and T.

Finally, the beam radius along the propagation path is plotted in Fig. 4, where the EC beam radius is about 14.09 mm at the center of plasma.

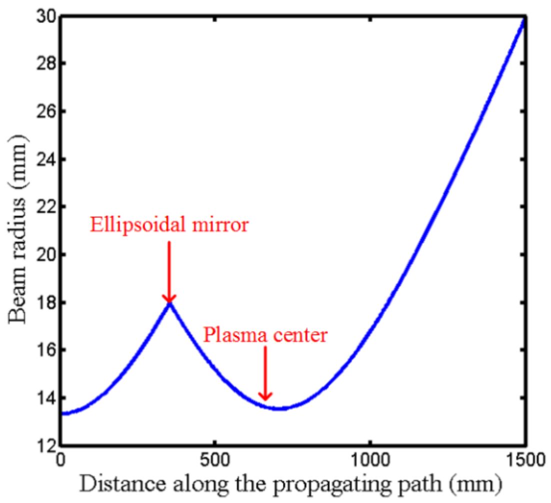

Fig. 4. Beam radius along the propagation path (plasma center, 589mm).

5. Conclusion

To expand the operation range of J-TEXT tokamak, a 105GHz/500kW/1s ECRH system is being developed. The system is based on the Gycom gyrotron, the transmission line with corrugated waveguides, and a quasi-optical launcher. Currently, the design of this system has been finished and all the subunits are on the way. The gyrotron will be delivered at the end of 2018, and the first commissioning of the ECRH system will be done at the middle of 2019. This ECRH system will be mainly used for plasma heating, transport, MHD stability, disruption avoidance, etc. We plan to carry out experiments with the 105 GHz ECRH system at the beginning of 2020.

Acknowledgments

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