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Conceptual design of CFETR electron cyclotron wave system

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HIGHLIGHTS

- The conceptual design of 170 GHz/20 MW electron cyclotron wave system was introduced.
- The layout of RF sources was given.
- The design and layout of transmission lines were shown and series of microwave components were introduced.
- The structure of launcher was described in detail.
- By the optic calculation and optimization of RF propagation inside the launcher, the quasi-optical parameters for launcher design were given. And then temperature distribution and thermal-stress of the injection mirror were analyzed.

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ABSTRACT

China Fusion Engineering Test Reactor (CFETR) is a test tokamak which is built for magnetically confined fusion plasma experiments. The electron cyclotron (EC) wave system of CFETR is designed to inject 20 MW RF power into the plasma for heating and current drive (H&CD) applications. The EC wave system consists of RF sources, twenty transmission lines (TLs) and one equatorial launcher. RF sources contain twenty gyrotrons with the output power 1 MW. There are series of microwave components distributed along the TL and the percentage of power losses of each TL is about 8.7%. In the equatorial launcher, five RF beams are injected into one focusing mirror and then reflected to the plasma via one injection mirror. The focusing mirror is spherical to focus Gaussian beam and the injection mirror which is flat can steer in the toroidal direction. After optic calculation and optimization, all the quasi-optical parameters for launcher design are given. Combining with the thermal stress analysis, the chosen inner diameter of water channel of injection mirror is 12 mm and the suggested water velocity is 3 m/s.

1. Introduction

CFETR is a test tokamak reactor with major radius R = 5.5 m, minor radius a = 1.6 m, plasma current I_p = 10–12 MA, toroidal field B_T = 4.5/5.3 T, elongation κ = 1.8, triangularity δ = 0.4 and thickness of blanket about 0.8–1.0 m. On the basis of existing physics and technology of International Thermonuclear Experimental Reactor (ITER), CFETR which is a good complementary with ITER works on the technology which can not be completed by ITER. The missions of ITER contain the overall programmatic objective and the principal goal. The overall programmatic objective is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes and the principal goal is to design, construct and operate a tokamak experiment at a scale which satisfies the objective. ITER is designed to confine a Deuterium–Tritium plasma in which α-particle heating dominates all other forms of plasma heating. The missions of CFETR are the demonstration of fusion energy production, the demonstration of tritium self-sufficiency with Tritium Breeding Ratio (TBR) ≥ 1.2, long pulse or steady-state operation with duty cycle time ≥0.3–0.5, the exploration of design options for DEMO blanket and divertor and the investigation of solutions for easy remote handling maintenance of in-vessel modules. Due to the need of high parameter steady state discharge operation mode, CFETR toroidal current is maintained by not only ohmic heating, but also electron cyclotron current drive (ECCD) [1], low hybrid current drive (LHCD) [2], ion cyclotron resonance heating (ICRH) [3] and neutral beam injection (NBI) [4].

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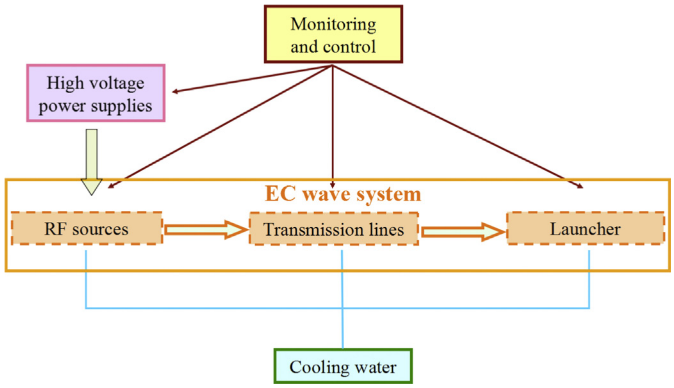

Fig. 1. The constitution of CFETR EC H&CD system.

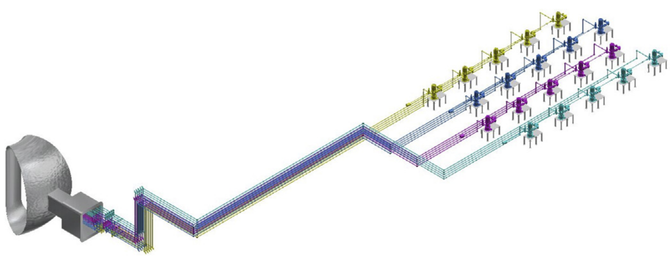

Fig. 2. The schematic layout of CFETR EC wave system.

The CFETR EC H&CD system is designed to deliver 20 MW radio-frequency (RF) power at 170 GHz into the plasma. CFETR EC H&CD system consists of EC wave system, monitoring and control, high voltage power supplies (HVPS) and cooling water supplies (Fig. 1). EC wave system includes RF sources, transmission lines and launcher (Fig. 2). Every two RF sources are fed by one high voltage power supply. The 20 MW power from RF sources is emitted to the launcher via TLs. Then the power is injected into the vacuum vessel of CFETR tokamak to heat and drive the current of plasma.

In this paper, the design and layout of RF sources, TLs and launcher are introduced in Sections 2–4. Finally, the conclusion is given.

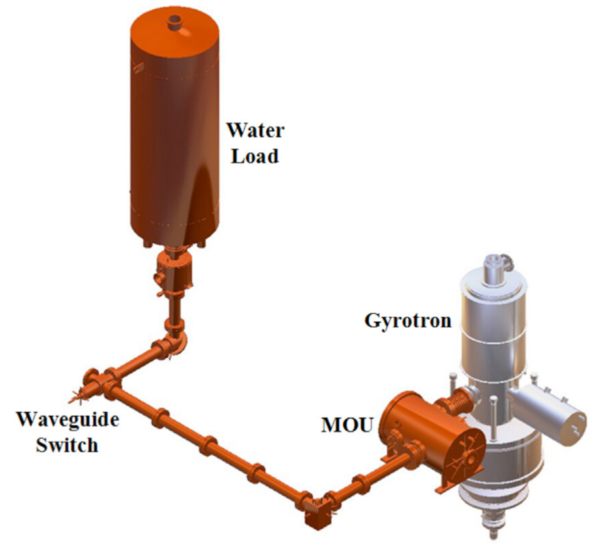

Fig. 4. The layout of one 1-MW unit.

2. RF sources

EC H&CD system of fusion installations is based on powerful millimeter wave sources—gyrotrons, which are able to generate microwave power up to 1 MW in very long pulses and 2 MW in short pulses [5–7]. Given the status of gyrotron development worldwide, the choice is made to base the design on the use of twenty 1 MW gyrotrons. Twenty gyrotrons are arranged in an array of 4 rows and 5 columns, as shown in Fig. 3. In order to avoid the interference and influence of magnetic field from adjacent gyrotrons, there is at least 5 m between every two adjacent gyrotrons. The gyrotrons between adjacent rows distribute crossly aiming at reducing total occupation space of RF sources.

The output power from the gyrotron is coupled into a circular corrugated waveguide whose diameter is 63.5 mm via a matching optics unit (MOU) [8]. There is a waveguide switch in each transmission line (Fig. 4), which diverts the RF power to a local dummy load for daily conditioning. When the RF power transmits into dummy load, all the power is absorbed by water.

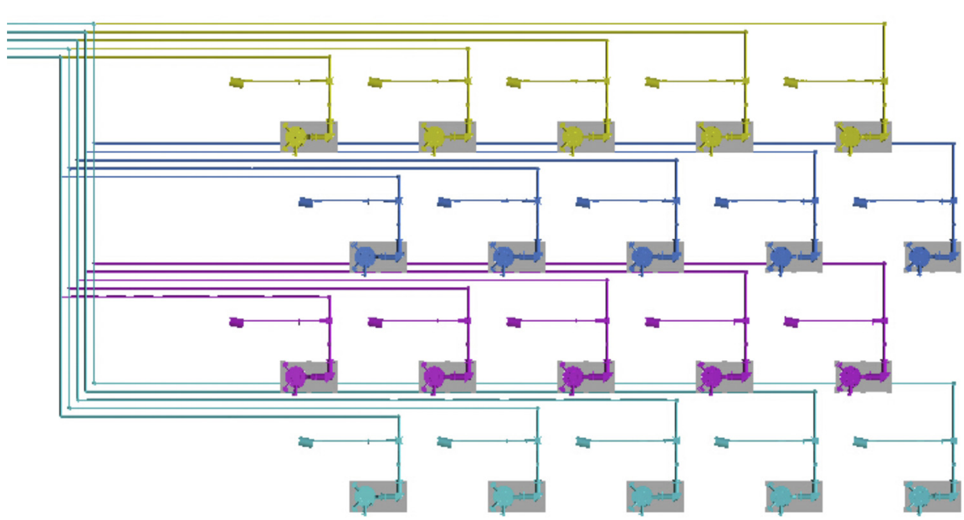

Fig. 3. Layout of RF sources: twenty 1-MW units.