ECRH on CFETR- Physics and Technology Needed

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Abstract: The Chinese Fusion Engineering Testing Reactor (CFETR) is the next device for the Chinese magnetic confinement fusion (MCF) program which aims to bridge the gaps between the fusion experiment ITER and the demonstration reactor DEMO. Operation scenarios have been assessed by integrated modeling based on advanced H-mode physics with high magnetic fields. High frequency electron cyclotron resonance heating will play a key role for H&CD and profile control. Concept design and some R&D activities are presented in this paper.

Introduction

The Chinese Fusion Engineering Testing Reactor (CFETR) [1-2] is the next device for the Chinese magnetic confinement fusion (MCF) program which aims to bridge the gaps between the fusion experiment ITER and the demonstration reactor DEMO. CFETR will be operated in two phases. Steady-state operation and tritium self-sustainment will be the two key issues for the first phase with a modest fusion power up to 200 MW. The second phase aims for DEMO validation with a fusion power around 1 GW.

Operation scenarios have been assessed by integrated modeling based on advanced H-mode physics with high magnetic fields (up to 7T). High frequency electron cyclotron resonance heating (170-230 GHz), lower hybrid current drive (5-7.5GHz), off-axis negative-ion neutral beam injection will be used together with high bootstrap current for achieving steady-state advanced operation.

Fully non-inductive CFETR scenarios have been developed with a self-consistent core-pedestal-equilibrium model. Table one is the baseline scenarios based on the integrated modeling. Different modelling of steady state operation conditions by the combination of ECCD with NNBI, ECCD with high field lower hybrid wave current drive were presented in this table. ECRH will play a key role for H&CD, NTM suppressing, and profile control to get necessary operation scenarios.

Table 1 Baseline steady state scenarios for CFETR

|                | Start point | Phase I   | Phase II  |
|----------------|-------------|-----------|-----------|
| \( R_0, a \) (m) | 6.6, 1.8    | 6.6, 1.8  | 6.6, 1.8  |
| \( P_{NBI}, P_{ECH} \) (MW) | 29.5, 10.0 | 35.8, 20.0 | 33.9, 20.1 |
| Fusion Gain \( Q_{FUS} \) | 2.9 | 3.0 | 14.9 |
Concept design for CFETR EC system

Concept design for CFETR EC system for Phase I has been done based on the ITER ECRH system. The first step is 20MW at 170GHz. Current drive efficiency, optical and engineering arrangements have been assessed from both top and mid-plan port. Table 2 shows modeling results for mid-plane port design. Four mirrors are used at different radial position (-67.5cm to +67.5 cm), toroidal and poloidal angles. Current drive efficiency of 29kA/MW was obtained at 170GHz. Total 600kA plasma current could be driven by 20MW EC power. 750kA could plasma current could be driven by 20MW EC power at 230GHz at Bt=7.0T from mid-plane port.

Table 2. Modeling results for the mod-plan port at 170GHz with 5.0T

| Height Za (cm) | -22.5 | 22.5 | -67.5 | 67.5 |
|----------------|-------|------|-------|------|
| Max. Icd (kA)/MW | 29.5  | 28.5 | 29    | 28.5 |
| Current density (MA/m²) | 0.6   | 0.55 | 0.55  | 0.45 |
| Optimum Φ | 200°  | 200° | 200°  | 200° |
| Optimum θ | 88°   | 94°  | 83°   | 98°  |

Similar simulation was carried out from top window injection which showed a higher current drive efficiency. Total 850kA plasma current could be driven by 20MW EC power at 170GHz with Bt = 5T. 1.5MA could plasma current could be driven by 20MW EC power at 230GHz with Bt=7.0T. Further optimization for get the best current drive condition is still under way.

The key sub-system is the antenna. Two options are under concept design which based on current developments of microwave antenna for ITER ECRH system. One is top window launcher and another one is the mid-plane antenna shown in Fig.1. Due to the limitation of space, beam combination will be used. 20 transmission lines which transfer 1MW power each from gyrotron are combined into the mid-plan port. By
combine 5 units into one which handle 5MW per mirror unit. Steering mechanism similar with that used in EAST will be adopted to have capacity for change the power deposition position and for real time NTM suppression. All components inside port are actively cooled with full shielding function. The first steering mirrors are equipped with shutter for preventing plasma contamination during plasma discharge and cleaning.

![Concept design for mid-plan port antenna](image1)

**Key components R&D**

The main technologies needed to fulfill CFETR EC mission are 170GHz/230GHz gyrotrons, long distance transmission, power supply, control and protection system and integrated antenna. Key components R&D started a few years ago, such as helium-free magnet, transmission line and key components, and gyrotron itself.

The first step is to develop a gyrotron shown in Figure 2 (a) with 0.5-1MW power and 5-10s pulse length at 140GHz. Fig.2 (b) is related low temperature superconducting magnet with a maximum field 5.8T. The magnets has been fully tested at 4.5K and meets the design requirement. The assembly and commission of the whole system of gyrotron for short pulse system will begin before the end of 2017. The following step for next 5 years is to develop the CW 1MW gyrotron at 170GHz and 230GHz in future.

The R&D of w/g components for CW evacuated transmission line is in good progress. To explore the feasible or optimum fabrication techniques, key prototype components, such as Multi-functional miter bends, pump out tee, bellows, DC break, and gate valve are currently being fabricated. The most difficult transmission line with corrugated geometry has been design, fabricated and tested. One meter and two meter corrugated waveguide transmission lines are technical ready for massive fabrication. High power gyrotron load with 1MW CW capacity is under development.

**Summary:**

The detailed physical modeling, concept design, research and development activities including R&D on ECRH system for CFETR haven been done for past few years. Modeling results showed a good performance by combination of ECCD, NNBI and
LHCD. Some key components, such as superconducting magnets, CW evacuated transmission line have been successfully developed. Gyrotron is under assembling and commissioning will start soon. The relative technology for experiments is under testing by using EAST ECRH experimental system [3-5] which is used as pre-testing for future CFETR.

Fig.2 (a) short pulse 1MW gyrotron (b) superconducting magnet

Fig.3 Key components for transmission line

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