3MW ECRH system and experiments on HL-2A

M.Huang, J.Rao, B.Li, J.Zhou, ZH.H.Lu, L.Y.Yao, Z.H.Kang, H.Wang, K.Feng, M.W.Wang, G.Y.Chen, Y.N.Bu, B.Lu, CH.Wang, X.Y.Bai, L.Zhao, H.Zheng, W.M.Xuan, X.R.Duan

Southwestern Institute of Physics, P.O.Box 432, Chengdu, Sichuan, 610041, China

1. Introduction

The 3MW ECRH system on HL-2A is upgraded step by step from 2005 to now.[1] Recently, four 68GHz/500kW/1s and two 68GHz/500kW/1.5s gyrotrons could be operated simultaneously on HL-2A. Continues or modulation ECW has been injected into HL-2A in O1 mode or X2 mode to explore plasma heating or current driving experiments based on the developed ECRH system. MHD instability, heat and particle transport had been studied during ECRH experiments.

2. 3MW ECRH System

The developed ECRH system consists of six 500kW subsystems, including six gyrotrons, six transmission lines and two launchers, shown in Fig.1.

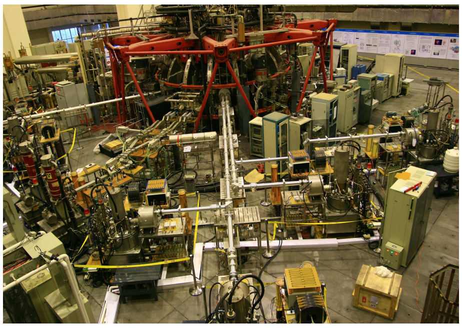

Fig.1 3MW ECRH system on HL-2A

2.1 Power Source

The main parameters of gyrotron, manufactured by GYCOM ltd., are listed in Tab.1.

Tab.1 Main parameters of gyrotrons

Output power	500kW after MOU	Frequency	68.2GHz
Mode purity after MOU	98%	Pulse duration	1s/1.5s
Output beam	Horizontal linear polarization, Gaussian beam		
Window	BN	Collector	Depressed
Cathode voltage	-53kV	Anode voltage	+20.8kV
Beam current	19.2A	Efficiency	50%

The performance of power supplies, arc protection, and control system had been improved to make the gyrotrons operate more stably and efficiently. The maximum output power with four gyrotrons after MOU could be up to 1.71MW/400ms and the maximum pulse duration is up to 900ms with 0.82MW output power. With the developed PSM power supply (80kV/100A/long pulse), six gyrotrons could be operated together.

2.2 Transmission Line

The transmission line includes MOU, oversized corrugated circular waveguide, miter bend with a plane mirror or a polarizer mirror, sliding waveguide and DC break, shown in Fig.2.[2] A sinusoidal grooved polarizer had been developed to realize O1-mode and X2-mode injection for different magnetic field. [3] With the low power test results, the X-mode purity of the polarizer reaches 85% and almost 100% when the toroidal angle is 15^{o}, which is the best angle for current drive.

Coupling efficiency, mode purity and transmission efficiency were increased based on the best quality of transmission line alignment and prevent arcs efficiently, which only occurred twice among 20 shots. 500kW/0.5s high power EC wave can be transmitted through the line with the polarizer in air and the transmission efficiency is over 90%.

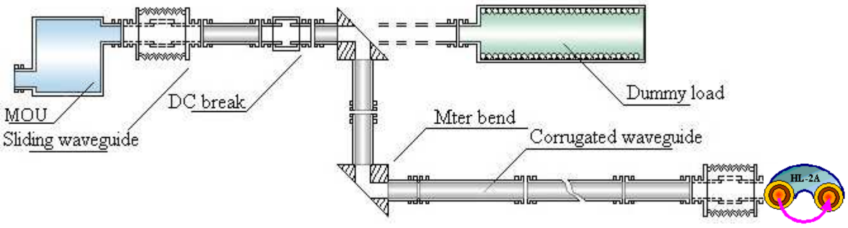

Fig.2 Scheme of transmission line of ECRH system

2.3 Launcher

The wave beams are injected into plasma from LFS by two launchers through two Φ350mm tokamak ports. One is for two beams (Fig.3(a)) and the other is for four beams (Fig.3(b)).

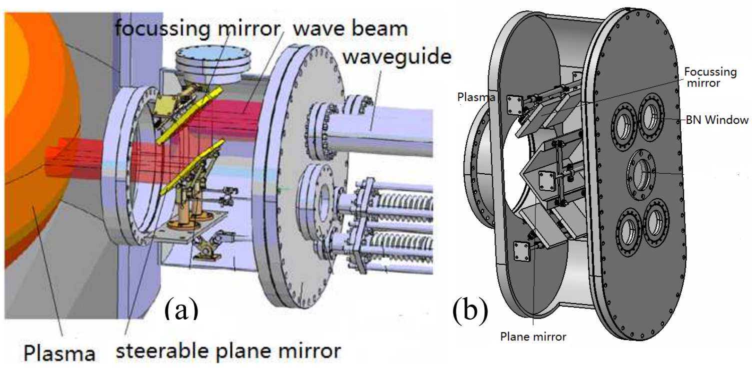

Fig.3 Launchers of ECRH system

The launcher consists of ellipsoidal focusing mirrors and plane mirrors.[4][5] The steerable plane mirrors in launcher (a) can change the toroidal and poloidal injection angle between 0-30^{0}. It is possible to explore on and off-axis plasma heating over half of the plasma radius and ECCD. The angles of plane mirrors in launcher (b) are designed to assure reflecting the beams to the center of the plasma. The beam radius is 37mm in the center of HL-2A, which can fulfill the requirements of localized heating and small enough for MHD control.

3. Plasma Experiments

In ECRH experiments, electron temperature T_e in central plasma of about 4.93keV has been achieved. ITB triggered by ECRH switch-off had been observed. When heating location is from q=1and q=2 surface, central temperature increased and edge temperature decreased after ECRH switch-off.

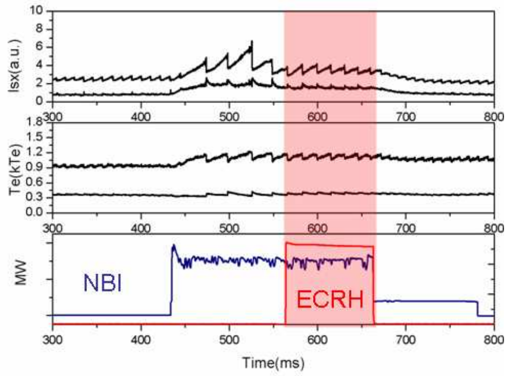

Fig.4 Sawtooth control with ECRH on HL-2A, P_{NBI}=0.7MW, P_{EC}=0.3MW

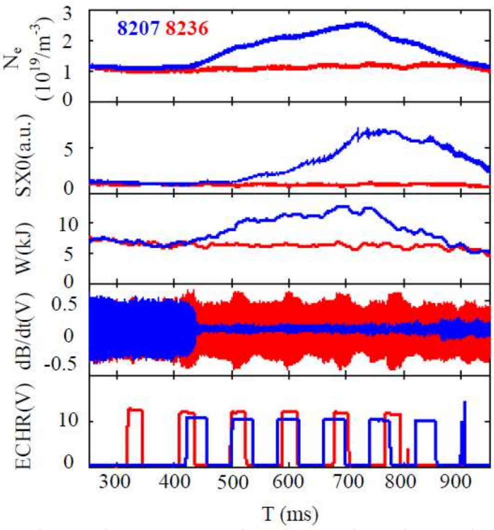

Fig.5 Time trances for 8207, the 2/1 mode is suppressed by successive ECRH and a case with 2/1 tearing mode(8236).

3.1 MHD behaviors

Sawteeth during ECRH tend to saturate or decrease in its ramp phase, and the sawteeth shapes are usually changed. Localized ECCD succeeded in destabilizing sawteeth which are stabilized by a co-existing population of energetic trapped ions in the core during NBI, shown in Fig.4.[6] The sawtooth period changed from 27ms to 15ms after ECRH.

Suppression of m=2/n=1 tearing modes with off-axis ECRH has been realized, leading to confinement improvement.[7] Plasma density, stored energy, and energy confinement time also increased, in Fig.5. The experiments results show that better effect of suppression can be achieved with such low frequency MECRH in vicinity of q=2 surface.

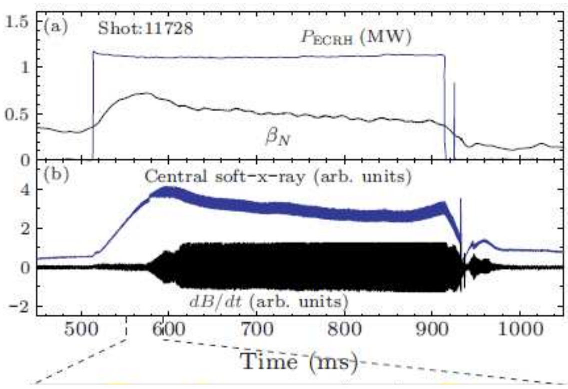

Fig.6 m/n=2/1NTM excited during ECRH, I_p= 160 kA, n_e= 0.76 × 10^{19} m^{-3}, B_t=1.26T

The m/n=2/1 NTM was excited with low density, low beta plasma with ECRH.[8] After ECRH switched on, the m/n=2/1 mode starts to grow and saturates at a high amplitude, shown in Fig.6(b). The deterioration of confinement produced by this mode is clearly observed on 15% decrease of β_N, shown in Fig.6(a).

3.2 Experiments with ECRH and NBI or LHCD

H-mode discharge with Type-III ELMs had been achieved by NBI and ECRH. [9] As shown in Fig.7, NBI is turned on firstly at 480ms. After ECRH being added at 670ms, D_α emissions rise and then drop dramatically and the H-mode appears. The plasma density, radiation power and energy increase continuously in energy confinement time just after

H-mode transition. The Type III ELMs with typical frequency of ~400 Hz can be sustained more than ten times of energy confinement time.

Better effect of the current driven was observed during synergy of LHCD and ECCD. Loop voltage decreased obviously and reflection power of LHW declined about 20%, which means the couple between LHW and plasma improved.

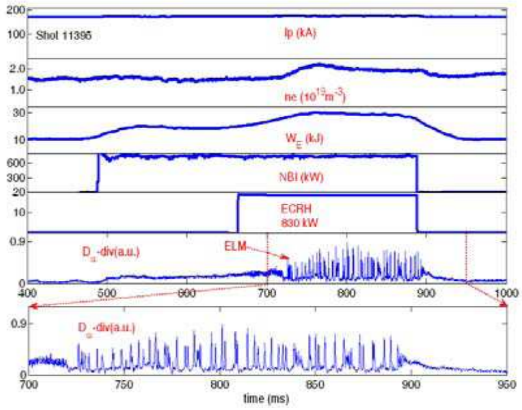

Fig.7 H-mode discharge with Type-III ELMs, PEC=0.83MW, PNBI=0.7MW,

4. Summary

3MW ECRH has developed on HL-2A and maximum 1.7MW EC power were injected into plasma. Series of ECRH experiments had been explored on HL-2A. Transient ITB after ECRH switch-off has been explored. Stabilization of tearing mode and sawtooth control with ECRH has been studied. NTM has been observed during ECRH heating. ELM H-mode discharge has been achieved with ECRH and NBI. Furthermore, the synergy experiments of ECRH/ECCD and LHCD or NBI had been explored on HL-2A. In the future plan, H mode discharge triggered by ECRH is proposed. Second-harmonic ECRH system, new real-time control launcher and polarizer are considering to provide more capability for physics study.

Acknowledgements

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