

ECRH system, microwave diagnostics and experimental results in the EAST tokamak

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Electron cyclotron resonance heating (ECRH), as a highly efficient and controllable heating tool, has been widely used in tokamak magnetic confinement devices [1]. Usually, the EC power can be injected as narrow Gaussian beams, which gives rise to highly localized power deposition. Consequently, ECRH and electron cyclotron current drive (ECCD) have been explored to an ideal candidate for local transport studies and for the control of various magnetohydrodynamics (MHD) instabilities occurring in tokamak plasmas. Unlike other RF heating techniques, EC wave can propagate in vacuum and the coupling is insensitive to the parameters at plasma edge, which suggests that the antenna can be located far away from the plasma. This advantage makes ECRH an attractive scheme for a thermonuclear device like ITER, in which, the launcher cannot be close to the plasma in order to avoid the material erosion and thermal damage.

EAST is a fully superconducting tokamak with a major radius of $R_0 = 1.90$ m and a minor radius of $a = 0.45$ m. The EC system will consist of a 4 MW continuous wave (CW) at 140 GHz (second harmonic of the extraordinary mode) for heating and current drive applications [2, 3]. In line with the long pulse operational capability of EAST, it was designed for a pulse length up to 1000 s. Benefitting from a pulse step modulator (PSM) type of power supply system it has a capability of fast modulation frequency up to 1 kHz. There are four gyrotrons produced by two different vendors, namely, No.1 and No.3 are provided by Russian company GYCOM, and the other two by CPI, USA. The specific parameters are shown in

Table 1. Specific parameters of gyrotrons

	No.1 and No.3	No.2 and No.4
Vender	Gycom	CPI
Type	Diode	Diode
Cavity mode	TE _{22,8}	TE _{28,7}
Max. output power	1 MW	900 KW
Pulse Length	100~1000 s	100~1000 s
Output beam	Gaussian beam	Gaussian beam
Collector type	Depressed	Depressed
Collector power limit	1.1 MW	1.8 MW
Cathode voltage	-46 kV	-59 kV
Beam current	43 A	40 A
Body voltage	+25 kV	+22 kV
Filament power	1000~1200 W	200~250 W

Table 1. The EC power will be launched from four mirrors located in the same port at low field side. In order to satisfy the physical need of changing power deposition in a large region, the launch angles can be continuously varied with range of over 30 degree in poloidal direction and ± 25 degree in toroidal as shown in Fig. 1. At present,

No.1 and No.2 gyrotron systems have been installed and the layout is shown in Fig. 2. However, only No.1 system has been used for plasma experiments.

Figure 3 shows a typical waveform of long pulse and high electron temperature discharge with ECRH. The magnetic field on the axis was set to be 2.5 T, in order to guarantee the EC power absorbed in the central region. The EC power of 0.4 MW was injected at $t = 3$ s and turned off at 102 s. The central electron temperature measured by Thomson scattering was high as $T_{e0} > 4.5$ keV during the EC heating phase. The contribution of ECRH to electron temperature can be found by comparison between pulse #59892 and pulse #59891 in which the plasma parameters and other RF heating power were the same. As shown in Fig. 4, the electron temperature is lowered by ~ 1.2 keV in the core region ($\rho < 0.25$) for pulse #59891 without ECRH.

Long pulse H-mode discharge with the combination of lower hybrid (LH), ion cyclotron (IC) and EC waves heating has been obtained in EAST. Typical traces of an H-mode discharge with ECRH ($t = 1.3\text{--}31.4$ s) and ECRH ($t > 31.4$ s) are illustrated in Fig. 5. It can be seen that when the EC power of about 0.3 MW was turned off at 31.4 s, the H-mode confinement phase was still maintained. However, the plasma stored energy (W_{MHD}) was decreased gradually from 145 kJ to 103 kJ, which indicates that ECRH is very important for high performance plasma. Besides, the loop voltage (V_{loop}) was increased slightly after EC power switched off, possibly resulted from the decrease in electron temperature which affects LH current drive efficiency significantly [4].

Microwave (MW) techniques such as quasi-optical reflector / lens, heterodyne detection, and lossless transmission line, are applied widely in plasma diagnostics on EAST, including the electron cyclotron emission (ECE) temperature measurement and the reflectometry for density and density fluctuation measurement. The ECE diagnostics consists of two radiometer systems and a Michelson interferometer [5]. The typical characteristics of the diagnostics are listed in Table 2. Thanks to the good spatial and temporal resolution, it can be used for investigation on MHD instabilities in addition to providing conventional temperature profiles. A new quasi-optical antenna with better poloidal resolution has been developed recently, which can be used for T_e fluctuation measurement in next campaign. The X-mode polarized Q-, V- and W-band reflectometries allow to measure the density profile from plasma edge to core [6]. These reflectometries featured by a high time resolution of 50 μs demonstrate the ability for study of pedestal physics on EAST as shown in Fig. 6. The systems are currently being upgraded to couple/decouple Q-, V- and W-band based on

quasi-optical method, and to use double-ridged horns with a broad band of 33–110 GHz for launcher and receiver.

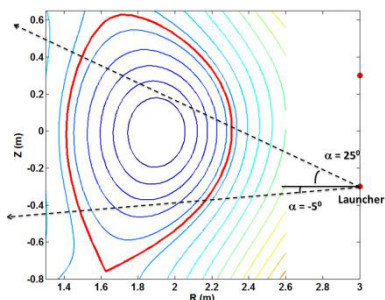


Fig. 1. EAST magnetic equilibrium and poloidal steering capability for the EC launchers at $Z = -0.3$ m. The red thick curve represents the lost closed magnetic surface

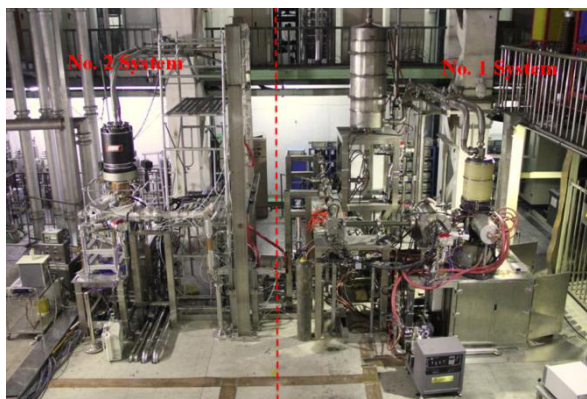


Fig. 2. The installed No.1 and No.2 gyrotron systems

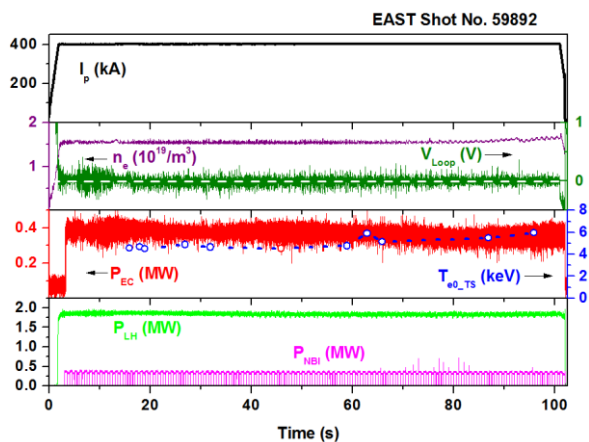


Fig. 3. Typical waveform of long pulse and high electron temperature discharge with ECRH

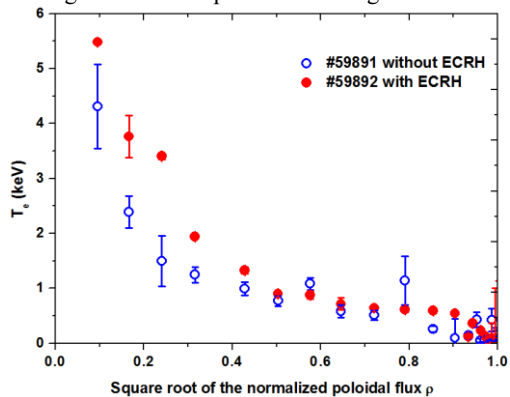


Fig. 4. Comparison of electron temperature profiles with ECRH and without it

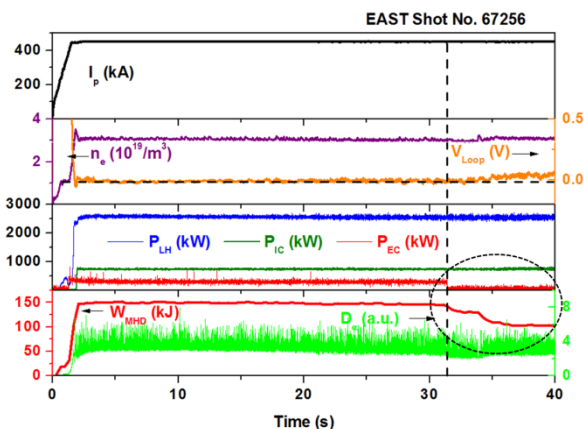


Fig. 5. Time evolutions of an H-mode discharge with ECRH ($t = 1.3\text{--}31.4$ s) and without ECRH ($t > 31.4$ s)

Table 2. Details of ECE diagnostics

Name	32-channel radiometer	16-channel radiometer	Michelson interferometer
Frequency coverage	104–168 GHz	97–120 GHz	80–500 GHz
Spectral resolution	0.5 GHz	0.2/0.5 GHz	2.8 GHz
Temporal resolution	2.5 us	2.5 us	30 ms

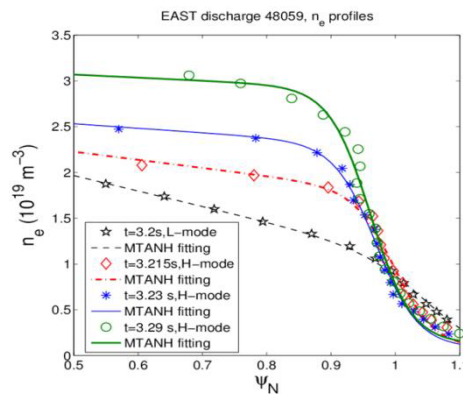


Fig. 6. An example of electron density profiles measured by fast frequency sweeping reflectometry

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