Tearing mode control by electron cyclotron resonant heating and current drive on EAST tokamak

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1. Introduction

The 140 GHz, 4 MW, 100 s ECRH/ECCD system [1] has been developed on EAST tokamak (with major radius of R_0 = 1.85 and minor radius of a = 0.45 cm). It consists of four gyrotrons with steerable launchers operating at second harmonic X-mode Electron Cyclotron wave. The launchers are installed at R = 3.0 m and Z = $\pm$ 30 cm, by which the maximum figure of merit for NTMs control is obtained. The first 1 MW system has been assembled and commissioned in the 2015 campaign. Its steerable mirror can be swept from -25°to +25°in the toroidal direction and from -5°below the horizontal plane to above +25° in the poloidal direction. In this paper, the first experimental results of tearing mode control by ECRH/ECCD on EAST tokamak are presented.

2. Stabilization of m/n=2/1 tearing mode by ECRH/ECCD

Experiment to suppress the tearing mode by applying the continuous EC beam injection has been carried out on EAST tokamak. The m/n=2/1 tearing mode naturally occurs in the L-mode discharge with 1MW LHW at the frequency of 2.45 GHz. The plasma parameters are I_p = 400 kA, n_{e0} ~2.0×10^{19} m^{-3}, T_{e0} ~1.5 keV, B_t ~ 2.2 T, q_{95} ~5. After the tearing mode grows naturally to its initially saturated size w_{int0}, the EC beam power is switched on to suppress the mode until its size saturates at w_{sat}. The mode size is estimated with the square root of the poloidal magnetic perturbation at the mode frequency, i.e. $w_{2/1} = \sqrt{\dot{B}_p f_{2/1}}$. It has been know that the mode size is about 0.15 a and locates at $\rho_{2/1}$ = 0.56 in this discharge. In the first step, the injection angle is fixed at ϕ = 180° in the toroidal angle and θ = 90° in the poloidal angle, and thereby the wave deposition position locates at ρ_{ECH} = 0.56 with the FWHM ~ 0.12 a, provided by the GA-TORAY code. The ρ is defined as the normalized toroidal flux radius in this paper. The injection power changes from 100 kW, 150 kW, 240 kW and

320 kW shot by shot. A reduction ratio in the mode size is defined as the saturated size w_{sat} normalized by the initial mode size w_{int0}. In the Figure 1(a), it is seen that the ratio decreases as the ECRH power increases and then almost saturates at 60%, indicating that the classical tearing mode cannot be suppressed completely by ECRH alone. This can be explained by the fact that stabilization mechanism comes from the temperature increase inside the magnetic island [2]. The smaller the island size is, the less the energy confinement is, in agreement with the numerical simulation [3].

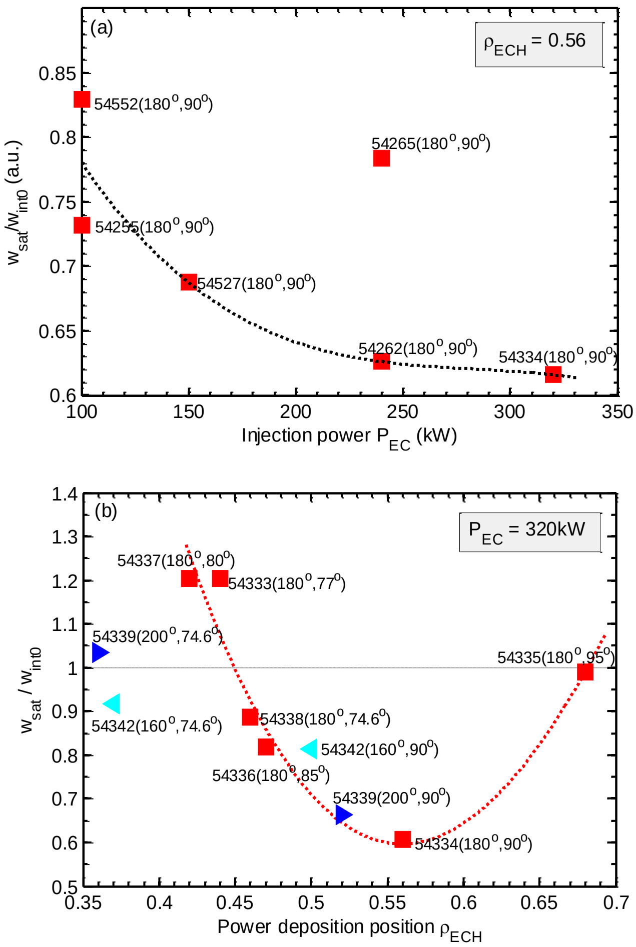

Figure 1. The suppression of m/n=2/1 tearing mode by applying the continuous EC beam injection with (a) different injection power at the same wave deposition position; and with (b) the injection power of 320kW at different power deposition position. The perpendicular beam injection produces pure ECRH effect (denoted by red square) and oblique injection has both heating and co-ECCD (blue triangular) or con-ECCD (cyan triangular).

In the second step, the injection power of EC beam is fixed at 320kW and the power deposition position moves radially from plasma center to the edge by adjusting the injection angle shot by shot. As shown in the Figure 1(b), the stabilization effect can be observed in a wider region from 0.45 to 0.67, but the destabilization effect is enhanced by heating the plasma core, possibly caused by the change of the plasma current density profile by heating or current drive and therefore the tearing mode stability index Δ'. As to the wave injection with angle of (ϕ=200°, θ=90°), its power deposition locates at ρ_{ECH} = 0.52. Since the deposition position of driven current is at ρ_{ECCD} = 0.44, which inwards deviates with $\Delta\rho$= 0.12 from the location of magnetic island, one can conclude that the effect on the mode size reduction comes from the ECRH rather than ECCD.

3. Control of m/n=2/1 tearing mode excited and locked by RMP

In order to investigate the ECRH and ECCD effects on the magnetic island 's O and X points in an experimental way, the external resonant magnetic perturbation (RMP) is applied to trigger and control the magnetic island rotating slowly in the Ohmic discharge. The plasma parameters are I_p ~ 400 kA, n_{e0} ~2.0×10^{19} m^{-3}, T_{e0} ~1.2 keV, B_t ~2.4 T, q_{95} ~ 5.6. A static n = 1 RMP is firstly applied with ramp-up current to determine the penetration threshold for generation of the m/n = 2/1 tearing mode, and then rotating RMPs with constant amplitude I_{RMPs} = 1.9 kA (above the penetration threshold) is imposed at the frequency of 1 Hz to regenerate and lock the magnetic island rotating slowly. The continuous EC wave is injected with fixed power of 400 kW, and the injection angle is adjusted from (180°, 88°), (180°, 90°) to (200°, 92°) shot by shot. The suppression ratio is defined here as $\eta = (\sqrt{B_{r,n=1}} - \sqrt{B_{r0,n=1}})/\sqrt{B_{r0,n=1}}$ to evaluate the mode size reduced by the ECRH/ECCD, in which $B_{r,n=1}$ and $B_{r0,n=1}$ are the amplitudes of radial magnetic perturbation of n =1 mode after and before ECRH/ECCD application. The dominant component n=1 harmonic has been evaluated by using Fourier decomposition of the response field, for which the contributed RMPs vacuum field and the eddy current have been excluded from the calculation. In the Figure 2, the suppression ratio is plotted along the toroidal angle of the radial magnetic perturbation of n =1 mode, with respect to three different injection angles. For the inwards radial deviation of $\Delta\rho$ = - 0.06, the ECRH contributed stabilization effect at magnetic island's O point is almost compensated by destabilization effect at the island's X point, and therefore the mode suppression is ineffective. For a smaller outward radial deviation, i.e. $\Delta\rho$ = + 0.02, the stabilization effect on the island's O point is significantly enhanced in the first period. However, this effect is reduced at the island's O point in the second period. It is found that this is because the q = 2 surface moves inwards due to the temperature increase and thereby change in the plasma equilibrium. As to the largest outwards radial deviation, i.e. $\Delta\rho$ = + 0.07, a weaker stabilization effect is enhanced most in the second period, comparing with the former two. Since very limited EC power is deposited at this position, the only possible contribution to the mode suppression comes from the driven current depositing at $\rho_{ECCD} = 0.57$. It illustrates that the ECCD plays similar or even more important role than ECRH on the mode stabilization in the low beta plasmas, different from the previous results on TEXTOR [4], and that the ECRH contributes to the movement of the q=2 surface and thereby makes the mode stabilization by ECCD enhanced.

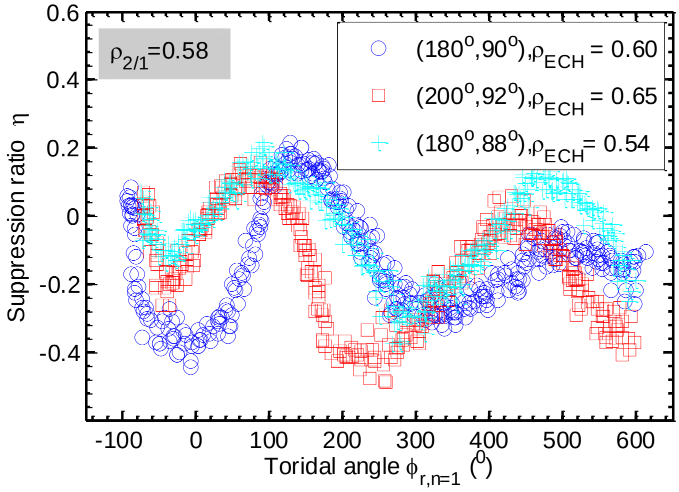

Figure 2. The suppression ratio of the mode size reduced by the ECRH/ECCD along the toroidal angle corresponding to the magnetic island's X and O point.

4. Discussion and summary

The experimental study shows that the classical tearing mode cannot be stabilized completely by ECRH alone. The stabilization (destabilization) effect on the magnetic island's O- (X-) point at different radial deposition position is investigated in deliberate experiments by the assistance of RMP to control the tearing mode rotating slowly.

Reference

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