Thermal Transport analysis for the High-$\beta_N$ Discharge on EAST

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Abstract

Experiments on EAST tokamak have been performed with high normalized beta and favorable energy confinement. The thermal transport properties of the typical High-$\beta_N$ discharge on the EAST tokamak is studied, and gyrokinetic non-linear simulation is carried out in this paper. Both of the ion and electron thermal diffusivities ($\chi_i, \chi_e$) normalized to Gyro-Bohm diffusivity decrease with $\beta_N$ increasing. The growth rate of electrostatic turbulence is increased with $\beta_N$ when $\beta_N$ is less than 1.5, and it is decreased when $\beta_N$ is up to about 1.7. Electrostatic turbulence is suppressed obviously by $\beta_N$ when it is up to 1.9. TEM transfers to ITG when $\beta_N$ is about 1.5.

1. Introduction

The normalized plasma pressure $\beta_N$ is a key figure of merit for high fusion gain operation in steady-state tokamak since the fusion gain $Q$, and the faction of bootstrap current ($f_{BS}$) are proportional to $\beta_N$.1,2 High-$\beta_N$, non-inductively-driven discharges are perfect candidates for future burning plasma devices. With stable high NBI powers of up to 28MW and low gas puffing, a new record in fusion performance has been achieved in JET-ILW.3 High-$\beta$ scenarios have also been developed in ASDEX Upgrade which favorably extrapolates to large devices like ITER and DEMO.4 Discharges with input power of around 4MW usually reached $\beta_N$ of 1.5~1.7 and $H_{98y_2}$ of 1.6~1.8. Discharge with higher input power of 8MW reached $\beta_N$ of 2.7, $H_{98y_2}$ of 1.3 and high bootstrap current faction of 0.84. The discharge with the highest $\beta_N$ has the nearest parameter range to the JT-60SA target. Since 2015, reproducible discharges with $\beta_N > 1.5$ were achieved on EAST.5 In this paper, thermal transport properties of the typical high-$\beta_N$ discharge is given by TRANSP and gyrokinetics simulation are also carried out.
2. Experimental setup

A typical high $\beta_N$ discharge on EAST are chosen for discussion. The plasma current is 400kA and the toroidal magnetic field is 1.56T. The LHW is injected at $t=2s$, as a result of which the loop voltage decreased by around 0.5V. Four of the available NBI sources were turned on in a specific order. With fully injection of 4.8MW NBI, $H_{98y2}$ reaches 1.1 and $\beta_N$ reaches 1.9 at around $t=4.5s$. $\beta_N$ is increased with NBI power obviously in LHW plasma, as seen in figure 1. $\beta_N$ becomes larger at 0.3s later of each NBI injection time.

![Figure 1. $\beta_N$ versus NBI input power at the injection time (stars) and 0.3s later of each time (cycle).](image)

3. Heat transport analysis for the high-$\beta_N$ discharge

To investigate the micro-turbulence properties at high-$\beta_N$ case, we use global gyrokinetic toroidal code GTC [6] to analysis. The realistic equilibrium is obtained from EFIT [7] and plasma parameter profiles are given by TRANSP. Figure 2 shows Logarithmic graph of three electrostatic modes at 3.7s, and electrostatic modes saturate at $t=40$ $(50*Cs/R_0)$ by non-linear simulation. TEM is dominant before $t=3.3s$, then TEM transfers to ITG, which can be seen from figure 3. Figure 4 shows the growth rate ($\gamma$) of three electrostatic turbulence modes with $\beta_N$ at different minor radius from core to edge at 3.7s. $\gamma$ increases first and then decreases with $\beta_N$. The electrostatic turbulence is effectively suppressed as $\beta_N$ grows up to 1.9.
In order to investigate the dependence of thermal diffusivities on the normalized beta, $\chi_i$ and $\chi_e$ normalized by Gyro-Bohm diffusivity are calculated by GTC, and their variation tendency are shown in figure 5. $\chi_i$ and $\chi_e$ decreases with $\beta_N$ when the turbulence is saturate.
4. Conclusions

Experiments on the EAST tokamak have extended the high-\(\beta_N\) scenario towards the steady-state burning plasma regime by the combination of NBI heating and LHW. The normalized beta reaches 1.9 and the energy confinement factor reaches 1.0. The ion temperature and electron temperature both become strongly peaked in the core during the higher \(\beta_N\) phase and leads to the ITB formation. The electron and ion thermal diffusivity, \(\chi_e\) and \(\chi_i\) decrease with \(\beta_N\). The gyrokinetics simulation results show that the electrostatic turbulence growth rate is increased with \(\beta_N\) first and then decreased. Electrostatic turbulence is suppressed by \(\beta_N\) when it is about 1.9. TEM transfers to ITG when \(\beta_N\) is about 1.5. Further study will be carried out to understand the electromagnetic turbulence during high-\(\beta_N\) discharges.

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References