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Suppression of MHD instabilities in the synergetic IBW plus LHCD HT-7 plasma

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It is noted that in the IBW heated HT-7 plasma, MHD instability can be postponed or suppressed effectively by the IBW wave heating, in the meanwhile the particle confinement is significantly improved with a density increase and a drop of H_α radiation in the edge. Benefit from such application, the MHD instability can be also suppressed or postponed in the synergy experiment of LHCD and IBW. Combining with good wall condition, plasma performance has been improved significantly. In this paper, such MHD instabilities and their suppression experiments are presented, and preliminary results are discussed.

1. Introduction

The HT-7 device is a medium-sized superconducting tokamak with a major radius of R=1.22m and is of a limiter configuration with two full poloidal limiters and one inner toroidal belt limiter, all of which are water-cooled and made of special doped graphite coated by SiC film with a minor radius of 27cm. Its major research fields focus on the exploration of advanced steady-state operation and high-performance plasma discharges. From 2004, two additional water-cooled toroidal double-ring graphite limiters located at the top and bottom of the inner wall are applied for steady-state plasma operation. Wall boronization or siliconization by means of RF producing plasmas is the routine first wall conditioning way during the experiments. To explore high performance plasma operation under steady-state conditions, a 1.2MW 2.45GHz LHCD system with a multi-junction coupler in the spectrum range of $n_{//}$=1.9-3.4, a 1.5MW ICRF system and a 0.35MW IBW system in frequency range of 18-30MHz with CW operation capacities have been applied to heat and drive the HT-7 plasma so as to realize active control of the current density and pressure profile.

In HT-7, MHD instabilities occur frequently in the some OH operation regime with plasma current of 100-120kA, electron density of 0.9-1.1×10^{13}cm^{-3} and toroidal magnetic field of 1.7-2.0T. During the plasma current platform, most of them are dangerous m/n=2/1 resistive tearing mode, which is driven by the plasma current density gradient. Usually they are quiet and not harmful in the OH discharge, but upon LHCD is launched into the plasma, these m=2 modes often grow and lock on the vacuum vessel and lead to plasma disruption. In some cases, it does not induce plasma disruption but cause degradation of the high-power-heated plasmas performance. Since partial of operation regime for HT-7 steady-state high performance plasma is located in same region, suppression or avoidance of m/n=2/1 resistive tearing mode instability is most crucial issue for the extension of advanced performance scenario. Two approaches by redistributing plasma current density profile through active external control of LHCD or IBW waves have been carried out in HT-7, one is dynamic stabilization of MHD perturbation by modulation of toroidal current, power or frequency of LH or IBW waves [1], and the other is variation of electron pressure profile by movement of IBW resonant layer. The latter way is presented in this paper, and preliminary results are introduced.

2. Suppression of MHD activity in IBW heated plasma

IBW experimental results in HT-7 have demonstrated that IBW wave is an effective way to heat electron globally and locally, control electron pressure profile, improve plasma confinement, stabilize MHD instabilities and suppress edge turbulence, which depending on the location of the ion cyclotron resonant layer in the plasma [2]. Fig.1 shows a typical discharge with efficient suppression of the MHD activity by the off-axis 24MHz IBW wave, in which the particle confinement is apparently improved indicating by a density increase and a drop of H_α/D_α radiation. Since in such experiments it is often observed that the local electron pressure profile was steeped at the region around the resonant layer, it is understood that off-axis IBW heating modifies the electron pressure profile, and then redistributes the current density profile, resulting in partial or entire suppression of the MHD instability [2]. In another experiments with on-axis 30MHz IBW wave, the particle confinement is greatly improved with a very peaked density profile as indicated by a sharp drop of H_α/D_α radiation, and the fluctuation at the plasma edge is also significantly suppressed from signal of Langmuir probe. As illustrated in Fig.2, MHD instabilities with m=2 or m=3 modes can be suppressed effectively by the on-axis IBW wave, in which these modes existed in the OH target plasma. Since the edge safety factor q_a is kept at around 3.2 in those experiments, m=3 mode is probably m/n=3/2 mode. It suggests that on-axis IBW wave is also of ability to affect MHD activities near rational surface like m/n=2/1 or 3/2 at the case of low q_a by varying electron pressure profile hence current density profile.

Experiments indicate that there is a power threshold of the IBW wave around 130kW for effects of both cases above. It means that it is possible to modify electron pressure profile and impact MHD activities by optimizing IBW off-axis heating through changing the toroidal magnetic filed strength to injecting IBW power near the rational surface.

3. MHD behaviors in synergetic LHCD plus IBW discharge

In synergetic discharge of off-axis LHCD and off-axis IBW, more than 80% of the plasma current was sustained by the LHCD and the bootstrap current. When the IBW resonant layer is near the rational surface, the improved edge and core confinement results in a large pressure gradient and large edge bootstrap current density, which often drives MHD instabilities and deteriorates the plasma performance or terminates the discharge. Fig.3 gives such a typical discharge, in which a weak m=2 mode appears upon the IBW wave launches into the off-axis LHCD driven plasma, and maintains while sawteeth activity on the central soft x-ray signal becomes strong, then these m=2 mode increases greatly after the sawteeth disappears and changes to Mirnov oscillation, resulting in mode lock and plasma disruption. By proper optimization of LHCD launched spectra, plasma parameters and toroidal magnetic field to decrease pressure steep to avoid these MHD activity, a normalized performance H_{89}>1.2 with β_N close to unity for nearly 8s and with an ITB-like profile of electron temperature profile and density, more than $400\tau_E$ has be achieved.

In synergetic discharge of on-axis LHCD and off-axis IBW for the steady-state high performance, it is very important to utilize the IBW local heating to increase the high-confinement volume [2]. In such experiments, LHCD is usually launched into plasma during the initial plasma current rise phase to obtain maximum gain. Since in the establishing phase of the plasma current, MHD mode varies greatly with evolution that firstly changes from m=5 to m=4, then to m=3, later keeps at m=3 mode or changes to m=2 mode, and finally decays after plasma current reaches the platform, which is well corresponding the evolution of the establishment of the q surface. The application of LHCD power will excite residual m=2 mode or transfers residual m=3 mode to m=2 mode, and then they locks causing plasma disruption. The application of the off-axis IBW wave can avoid or suppress occurrence of these m=2 modes. Same phenomena are also observed when the both waves injected into plasma during the plasma current platform. Benefit from this contribution, the normalized performance $\beta_N H_{89}$>2 have been achieved for duration of $50\tau_E$.

Acknowledgements

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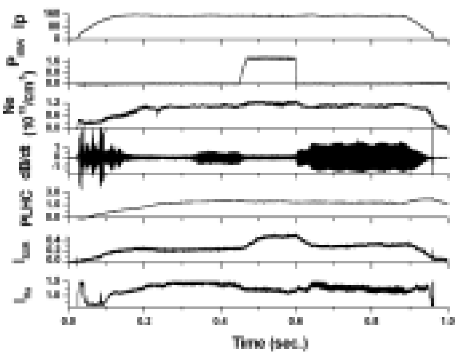

Fig.1 Suppression of MHD instability by 24MHz IBW wave (Ip=157.6kA, Bt=1.76T, P_{IBW}=156kW, qa=3.1, the IBW Ω_H or $2\Omega_D$ ion cyclotron resonant layer is located near 0.5a)

References

1. Jianshan Mao, P.E. Phillips, et al., Nucl. Fusion, 41, 1645, 2001
2. Baonian Wan and Jiangang Li for HT-7 Team, Nucl. Fusion 43, 1279, 2003

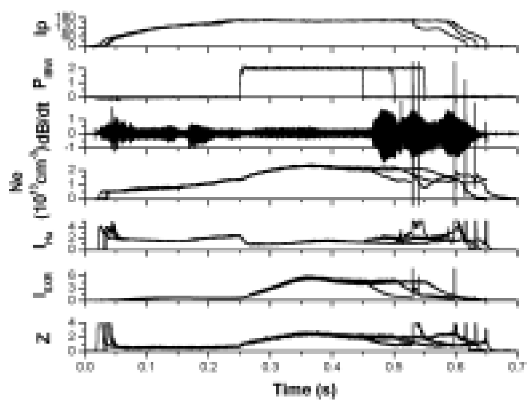

Fig.2 Suppression of MHD instability by 30MHz IBW wave (Ip=168kA, Bt=1.99T, qa=3.2, P_{IBW}=195kW, the IBW Ω_H or $2\Omega_D$ ion cyclotron resonant layer is located in the plasma centre).

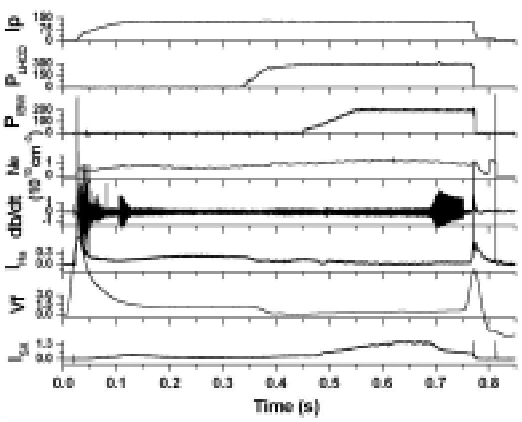

Fig.3 MHD behaviors in the synergy of off-axis LHCD and off-axis IBW plasmas (Ip=158kA, Bt=1.77T, qa=3.75, P_{LHCD}=320kW, P_{IBW}=195kW, 30MHz, $2\Omega_D$ is near -0.5a, $5/2\Omega_D$ is near 0.53a)