Recent Experiment Progress on the HL-1M Tokamak

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Abstract Experiments on the auxiliary heating, fueling of plasma and wall conditioning were carried out on HL-1M. ECRH experiments were conducted successfully with T_e increase more than 50%. The double sawtooth in soft X-ray radiation were observed, which imply that the reversed magnetic shear could be formed during ECRH. An eight-shot pellet injector (PI) was used for experiments. After the pellet injection, a hollow electron temperature and peaked density profile were obtained, accompanied with the increase of energy confinement time. The pellet ablation process was investigated with a CCD camera and an H emission detector array. Obviously asymmetry in the pellet cloud was observed in both the toroidal and poloidal direction. It is found that the velocity of pellet is slowed down obviously after the pellet enters into the plasma. The safety-factor q-profile was estimated with the inclination angle of ablation cloud with respect to the torus. Density limit investigations have been performed at different wall condition with three kinds of fuelling methods. It is found that higher density limit can be achieved in following conditions: one is the strong reduction of the impurity content after siliconization, another is the peaked density profile with pellet injection and/or SMBI. With a NBI system of 1MW, preliminary results of NBI experiments were obtained with increase of ion temperature from 600eV to 800eV.

1. Introduction

Main objectives of the HL-1M tokamak are to conduct experiments on high power auxiliary heating and current drive and to explore new fueling techniques in order to develop the physics and technology basis for next tokamak, HL-2A, which is a modification of the ASDEX from IPP at Garching, Germany. Up to now, the maximum parameters of HL-1M (R=1.02m, a=0.26m) are: I_P=320kA, $n_e=8\times10^{19}m^{-3}$, $B_t<3T$ and discharge duration of 4 seconds.

To realize the objective of the device, many advanced diagnostics with high time-spatial resolution were developed, including a 2mm ECE heterodyne receiver with 20 spatial points and time resolution of 2ms, a 15 channels bolometer with fast response time of 5μs, A high speed CCD camera with minimum exposure time of 0.1μs for the study of pellet ablation process and a laser blow-off for impurity transport research.

In the past a few years, the plasma performance of the HL-1M tokamak has been improved significantly with wall conditioning [1]. The confinement improvement by LHCD was investigated extensively and the ion heating by LHW was achieved [2]. In the over past two years, experiments on the auxiliary heating, fueling of plasma and wall conditionings were carried out on the HL-1M. Experiment progresses in many aspects were made. The reversed magnetic shear(RMS) configuration was obtained in the different scenarios of experiments [3], including off-axis ECRH, LHCD and the plasma current ramp-up control combined with supersonic molecular beam injection(SMBI). On the fueling technique, besides pellet injection, a new fueling method, supersonic molecular beam injection was developed in our laboratory, which can significantly improve the efficiency of fueling and plasma performances. These results on RMS and SMBI are reported in companion papers at this conference [3][4]. In this paper, the main experiment results on the off-axis ECRH, pellet injection, density limit and NBI will be presented.

2. Off Axis ECRH Experiments

With a gyrotron of 75GHz /300kW, ECRH experiments were performed successfully with perpendiculary injection of RF power from low field side in an ordinary mode (o-mode). The typical plasma parameters for the ECRH experiments are as follows: plasma current I_P=150-200kA, line average electron density n_e=0.5-4.0×10^{13}cm^{-3}, toroidal field B_t=2.4-2.7T which corresponds with the resonance position from 10cm off-axis at high field side to the plasma center.

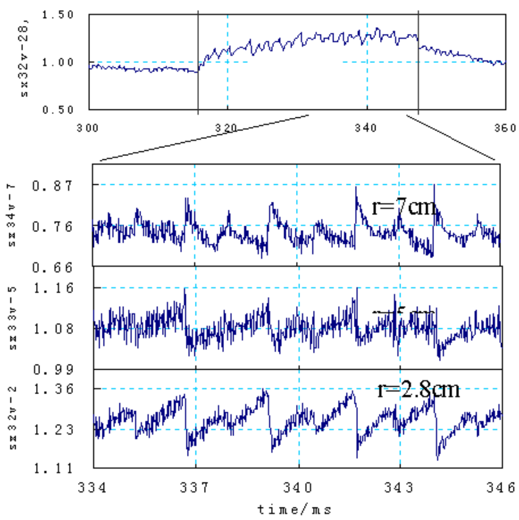


FIG. 1 Double sawtooth in soft X-ray radiation during ECRH

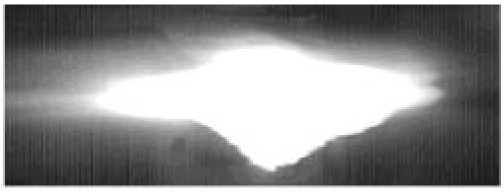
During ECRH the electron temperature T_e increased more than 50%, which measured by the 2mm ECE heterodyne receiver. With calibration by a soft x-ray energy spectra analyzer, the absolute electron temperature was found to be increased from 450eV to 700eV for typical case. The heating efficiency was found to depend strongly on the resonance position and obviously on the electron density. The heating efficiency was higher in the density range of 1.5-3.0×10^{13}cm^{-3} while the resonance layer was close to plasma center. It was found that the heating efficiency for o-mode injection from low field side is much higher than that for o-mode or x-mode from top injection at high field side.

The MHD activities were modified significantly with ECRH, both period and amplitude of the sawtooth in soft X-ray radiation were changed. Furthermore, the compound (double) sawteeth in soft X-ray radiation were observed as shown in Fig.1. The double sawtooth can be explained as a results of two q=1 surface existing in the plasma due to the off axis ECRH, which means that the reversed magnetic shear is formed [3].

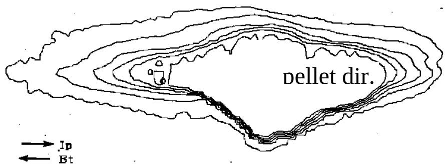
3. Pellet Injection Experiments

A pellet injector with up to 8 pellets was used for fuelling experiments with three different sizes of 2×ϕ1.0mm, 3×ϕ1.2mm, 3×ϕ1.3mm. The density rising in step was obtained with the 8-shots pellet injector. After the pellet injection, a hollow electron temperature profile and peaked density profile were observed by ECE and 6 channel FIR interferometer, respectively. In this case, the energy confinement time and particle confinement time was increased significantly. Typically, the particle confinement time is increased by twice. The density limit enhanced also, which will be discussed in next section.

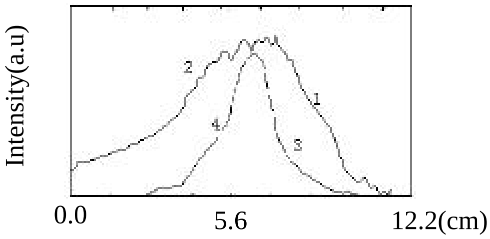
The pellet ablation process was investigated with a CCD camera and an H_α emission detector array. A hydrogen pellet ablation cloud image, taken by the CCD camera, is shown in Fig.2. It is seen from the contours of the H_α emission in Fig2.(b) that the pellet cloud was obviously asymmetry in both the toroidal and poloidal direction. The decay length of the cloud luminosity at the ion side is much longer than that at the electron side, which seems reasonable because a stronger heat flux impinges on the pellet from the electron side. The poloidal asymmetry of the ablation clouds may be related with poloidal drift motions.



(a) pellet ablation cloud



(b) Contour line of the intensity of ablation cloud



(c) Toroidal (solid line) and poloidal (dashed line) emission profile

FIG. 2 Asymmetry in the intensity of pellet cloud

The pellet penetration depth and velocity in plasma were measured with the 20 channels H_α emission detector array, which is mounted in the same cross section with pellet injection port. During the pellet ablation, the neutral gas cloud is always around the pellet, so the strongest point of H_α emission can indicate the location of the pellet. The evolution of radial profiles of the H_α emission is obtained with the Abel inversion of the multi-channel H_α signals, as shown in Fig.3(a), its contour plot is shown in Fig3(b). It is found that the velocity of pellet is slowed down obviously after the pellet enters into the plasma, typically from 800m/s to 730m/s. The slowdown of the pellet can be explained with a pellet ablation model [5]. During the pellet ablation, the neutral particles outside the ablation cloud are ionized rapidly,

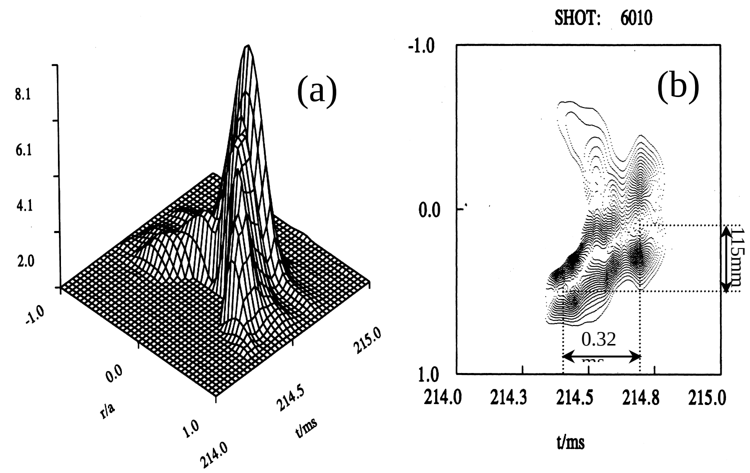


FIG. 3(a) The evolution of radial profile of the H emission during pellet injection. (b) The contour for (a) electrons and ions shift along opposite direction, resulting in a electric field. Thus the pellet will suffered a resistance due to E×B force, its velocity will be slowed down.

The pellet clouds are elongated in the magnetic field direction, which allows the use of the ablation cloud images to determine the current profile. By multi-exposures with CCD camera during a pellet ablation, the safety-factor q-profile was estimated with the inclination angle of ablation cloud with respect to the torus on HL-1M.

4. Density Limit and Wall Conditioning

Density limit investigations have been performed at different wall conditions with three kinds of fuelling methods, that is, gas puffing, pellet injection and supersonic molecular beam injection(SMBI) on HL-1M. With improved wall-conditioning technique, well-repeated ohmic discharges with high plasma current up to 200kA were realized. It was found that SMBI is much more effective than gas puffing to get higher density. In this case for I_P~100kA the density limit on HL-1M is just over Greenwald limit, for I_P~200kA the density limit is about 80% of Greenwald limit, as shown in Fig. 4. On HL-1M, boronization, siliconization and lithium coating have been used to improve plasma performance. The siliconization is commonly used on the HL-1M because its convenience and non-toxicity. The siliconization was performed by using the helium glow discharge with SiH_4 mixture. It is found that higher density limit could be achieved under following two conditions: one is the strong reduction of the impurity content after siliconization, another is the peaked density profile with pellet and/or SMBI, the latter reduced the interaction between plasma and wall.

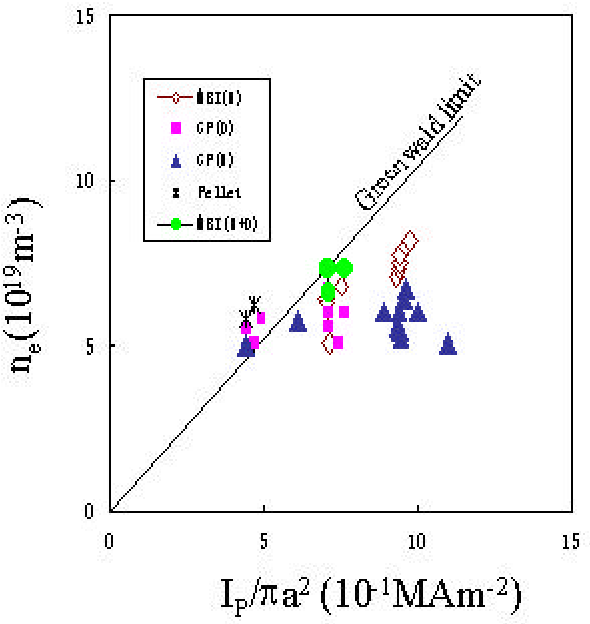


FIG. 4 The density limit versus I_p for gas puffing(GP) molecular beam injection and pellet injection

5. NBI Heating

Neutral Beam Injection (NBI) heating is thought to be most promising auxiliary heating method due to its high efficiency and less limitation for future fusion reactor. A NBI system of 1MW was built up on HL-1M with perpendicular injection from the outboard midplane of the tokamak. The beam accelerating voltage of 22kV and hydrogen ion beam current of 50A have been achieved for the beam line. In the NBI experiment, the central ion temperature, measured by a neutral particle energy analyzer with charge exchange, increased from 600eV to 800eV for typical case at 400kW of ion beam power. In higher power injection, plasma current was terminated by the impurity due to the sputtering from the graphite tile, which was used as beam dump. We are trying to solve the problem.

6. Summary

Over the past two years, experiment progresses in many aspects, such as the auxiliary heating, fueling and wall conditioning, were achieved on the HL-1M tokamak. ECRH experiments were conducted successfully with T_e increase more than 50%. The double sawtooth in soft X-ray radiation were observed, which imply that the reversed magnetic shear could be formed during ECRH.

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Density limit investigations have been performed at different wall conditionings with three kinds of fuelling methods. It is found that higher density limit could be achieved under following conditions: one is the strong reduction of the impurity content after siliconization, another is the peaked density profile with pellet injection and/or SMBI.

With a NBI system of 1MW, preliminary results of NBI experiments were obtained with increase of ion temperature from 600eV to 800eV.

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