EXPERIMENTAL RESULT OF PELLET FUELING IN HL-1M

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1. Introduction

The density profile control and confinement improvement in tokamak is one of the most important issues in nuclear fusion study.   In recent years, pellet injection has been developed rapidly and widely used in experimental fusion physics studies [1, 2]. Pellet fueling (PI) can deposit the fuel particles in the plasma core which produce peaked density profiles, reversed shear and higher fusion reaction rate for fusion reactor.

The pellet fueling experiments had been carried out on HL-1 in 1992. From 1993 one Eight-shot Pellet Injection (EPI) system has been proposed and developed under collaboration between State Technical University (STU) St Petersburg of Russia and SWIP [3].   The multi-shot pellet fueling experiments have been carried out on HL-1M and the experimental results are presented.

2. Pellet Injector and Experiment Setup

The EPI is a pneumatic multi barrels injector, capable to fire up to eight pellets(Φ0.9mm one, Φ1.0mm three,Φ1.4mm four barrels) with velocity of 500~1100m/s. The HL-1M is a circular cross section tokamak with R=1.02m,a=0.26m. In Pellet Fueling (PF) discharges the pellets were horizontally injected along a major radius. The device was operated in range of B_t=2~2.5T, I_p=100~160kA, target plasma n_e=0.3~2.0×10^{19}m^{-3}, T_e=600~1000eV. The gas puffing was shut-off, so the plasma performance was independent of gas puffing.

2.1 The Peaked Density Profile and improved confinement

The peaked density profile and improved confinement are typical feature in PF discharges. The features of n_e(r) strongly depend on pellet injection parameters and wall recycling conditions.

(a) Discharges in low recycling

In HL-1M, after the wall conditioning with siliconization and helium glow discharge cleaning, the wall hydrogen recycling was lower (V_L<0.3V). In above condition only, the HL=1M device can accept up to 8-pellets injection In 5463# shot the pellets is fired in sequence with Φ0.9mm 1st, Φ1.0mm 2nd to 4th,Φ1.4mm 5th to 8th. As shown in Fig.1, a very small perturbation of density without peaked profile was produced by the first small(Φ0.9mm) pellet and it only occurred in a region of r=11cm to r=-6cm. This observation has also been confirmed by H$_\alpha$ detector array. For the
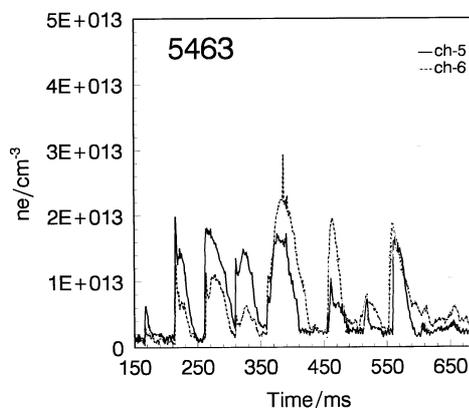

Fig. 1 Behavior of density profile with 8-shots pellet injection

second pellet injected the peaked n_e occurred at ch4 (r=7cm) and the sharp increase of n_e can still be measured in each chord until the third pellet was injected. From the 4th to the 8th pellets injected, n_e can be measured only in ch5(r=11cm) and ch6(r=15cm) while the sharp increase of density is replaced by a variance with slowly rise and decay. The density can't be measured in ch1 to ch4 due to the inner disruption, so in Fig.1, the results shown are given only from ch5 and ch6. In this shot the W_p achieved only to 3.5KJ and τ_e=16ms.

(b) Discharges in High Recycling (DHR)

In HL-1M vessel graphite tiles cover about 6% of the inner surface. With increasing of discharge times the tiles become a new gas source and the background n_e rises automatically. In the DHR the density evolution of PF plasma was different as shown in Fig.2. In each chord, sharp rise of density up to the first maximum value n_{e1max} appears firstly and then rapid decrease follows. At outer region the decrease of density in 10ms was followed by a slowly rise up to second maximum value n_{e2max} (less than n_{e1max}) in 15 ms, and then n_e slowly decreases again. In center region(r=0cm) only a small decrease of n_e appears in 5 ms, then it keeps constant in 15ms and slowly decays after that. In high field side (r=-6cm, ch1) the n_e decreases continuously.

When the 2nd and 3rd pellet was injected, the second rise n_e in ch6 lasts in longer time and has a value even higher than the first value. In center ch2 the n_e either keeps nearly constant in value or has a second max value, but in ch1 it keeps in tip shape. The facts that $n_{ech1} \geqslant n_{ech2} \approx 2n_{ech6}$ and the appearance of a second rise of n_e in ch6 and even in ch2 are characteristics of this kind of DHR. The same behavior has also been seen in the 5290# in which the parameters of the pure PF discharge Wp=6.0KJ τ_e=26ms n_e(0)=5.3×10^{13}cm^{-3} have been obtained with 3pellets (Φ1.0mm) injection which the shot interval time is 50ms.
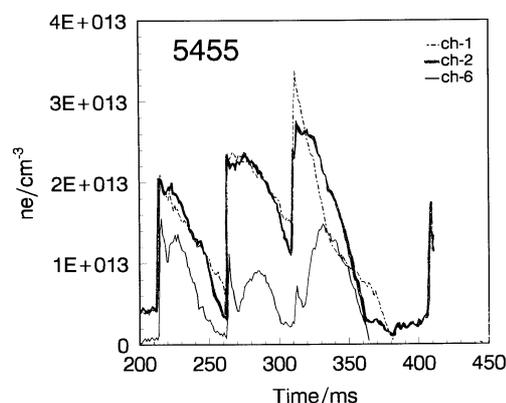

Fig. 2 Behavior of density profile with 3- shots pellet injection in DHR

2.2 The Peaked Profile of Soft-X ray and MHD Activity

Besides from the perturbation of $\delta n_e/n_e$ introduced by PI, the SX emission and MHD activity are greatly influenced by pellet penetration depth. As shown in Fig.3, for shallow penetration, the m=2MHD activity has been observed, and the peaking of Soft X-ray (SX) profile is nowhere high enough. For the situation that pellet penetration is medium and the deposit of particles is outside the sawtooth reversion radius r_s, small sawtooth oscillations have been found riding on the SX signals that limits the density peakness. For central penetration, the sawtooth activity can be completely suppressed in a period of 20~50ms with a simultaneous increase of central SX radiation, characterizing a pressure profile that peaked strongly around the magnetic axis (inside the r_s). It seems that the q=1surface behaves as a transport barrier causing the density and pressure profile peak strongly inside.

When the large (1.4mm) pellet injected, the T_e decreased to its 1/4 or 1/5 of original values, the profile goes flat obviously, and sometimes a hollow profile can be detected by ECE system. The dip of the T_e appears at r=-4cm. This position is similar with the density peaked center as mentioned above.

The T_e decreased in PF although, but the ion temperature T_i was increased. The particles
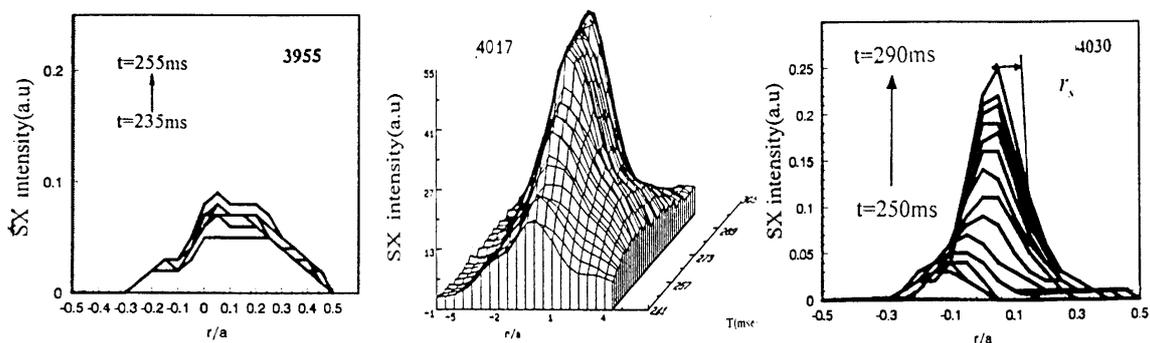

Fig. 3 Time histories of the SX signals and Abel inverted SX emission profiles for three pellet injected discharges [I_p = 100 ~ 150kA, B_t = 2.2 ~ 2.4T], pellet penetration becomes deeper from the left to right column

with different energy spectrum were accounted by a Neutral Particle Analyzer (NPA). In plasma center, under the heat-dynamic equilibrium the rise of T_i could be obtained by Maxwell evolution. Usually the T_i increased from 350ev up to 650~700ev, so this may be one reason for increment of W_P.

2.4 The Performances of Edge Plasma

In HL-1M PF discharges the edge plasma parameters were measured by the Langmuir probe array. The edge plasma n_e increases from $3 \times 10^{17} m^{-3}$ up to $1~3 \times 10^{18} m^{-3}$, while the T_e drops from ~25eV to ~12eV. In the DHR the increase of edge n_e was 2~3 times higher than that in DLR, inducing a variance of column $n_e(r)$.

During PF a Mach probes were used to measure the Mach number M of edge plasma toroidal flow, the poloidal flow velocity V_{pol} and the plasma potential V_f. The V_f is characterized by very large rapid change the M and the V_{pol} are reversed. A negative maximum value(~11km s^{-1}) of V_{pol} appears at r=25cm and the results are in agreement with the measure from the Doppler shifts of the H_α line by means of a high-resolution spectroscopic detector array. These phenomena are similar to the observations on JIPP TII-U tokamak[4].

4.6 The Observation of Pellet Ablation Process

The observation of pellet ablation cloud in plasma by a CCD camera has been carried out in HL-1M, some image photos of pellet ablation cloud in different region as shown in Fig.4.

Fig. 4 The frames showing the pellet ablation by the CCD camera. The pellet was broken (left)
The pellet ablation in the outer region (medium) and in the center region (right)

In the edge region the pellet ablation rate is low due to low n_e and T_e the emission of ablation cloud was weak. Sometimes only a few flash spots in the photo caused by pellet break. In the outer region, the ablation cloud has a circular shape the influence of toroidal magnetic field on it is not clear. In the center region, the toroidal magnetic field strongly influenced on the ablation cloud shape, for the large integrated pellet (barrel 4#) injection, the elongation of pellet cloud along the field line is evident. In this situation the image of the cloud always keeps integrated shape. However, the density perturbation was so large and rapid that measuring n_e in the central region is prevented. It may be caused by the internal disruption as observed on HELIOTRON E PF experiments [5]. From these photos we can also understand that, why the same size pellets injected caused different density perturbation. The break of pellet is the main reason.

3. Conclusion and discussion

(1) With HL-1M wall siliconization, helium glow discharge cleaning and low recycling, the continuous eight pellets with proper fire interval (more than 50ms) can be injected into the machine but the better parameters of plasma were not be obtained in these conditions.

(2) In high wall recycling condition, parameters $n_{e(0)}$=5.3x10^{13}cm^{-3} Wp=6.0KJ τ_E=26ms were obtained with three small pellet injection. For more or large pellets injection the internal disruption influenced further measure of density in plasma center region.

(3) The variance of potential and rotation velocity of boundary plasma and the deep particle deposition by pellet fueling are the main demands for improving confinement.

(4) The discharge parameter (I_P Q_a) should be further adjusted in order to meet the demands of continuous and intensive injection of large pellets.

Acknowledgment

Reference

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