

ABLATION CHARACTERISTICS ON THE OFF-AXIS PELLETT INJECTION WITH/WITHOUT NBI HEATING IN THE JIPP T-IIU TOKAMAK

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1. Introduction

Pellet ablation characteristics has been investigated in the off-axis ice pellet injection with/without NBI heating in the JIPP T-IIU tokamak. In addition, the dependence of the energy confinement time of the plasma on the pellet injection-angle has been examined.

A long “helical tail” of ablation light has been observed when an “injection-angle controllable system” has been applied to ohmically heated plasmas [1]. In the case of an injection angle (θ) larger than a certain value ($\theta \geq 4^\circ$), a pellet penetrates straightly through the plasma with a trace of straight ablation cloud. On the other hand, in the cases of on-axis injection and off-axis injection with the angle smaller than the certain value ($\theta \leq 4^\circ$), a long helical shape (“tail”) of ablation light has been observed by CCD cameras. The direction of this helical “tail” is independent to that of the total magnetic field lines of the torus. From the injection-angle controllable experiments as to four conditions with the combination of two (clockwise and counterclockwise) toroidal magnetic field directions and two plasma current directions, it has been found that the “tail” poloidally rotates in the electron diamagnetic direction, and toroidally in the opposite to the plasma current direction as to almost all conditions of injection angles.

In the present paper, two kinds of new experimental results obtained with these various injection angles are described. (1) As to ablation characteristics (“tail-shaped” phenomena) in the NBI plasma, it is found that the ablation cloud rotates to the same direction in the ohmically heated plasma in the case of off-axis upward injection. (2) As to energy confinement characteristics in the ohmic plasma, it is found that the energy confinement times in the cases of on-axis injection and the off-axis upward injection (i.e., to the inverse direction against the electron diamagnetic direction in poloidal plane) are better than that in the case of off-axis downward injection (i.e., to the parallel against the electron diamagnetic direction in poloidal plane).

2. Relation between energy confinement time and injected pellet position

An ice pellet is injected shot by shot at various injection angles, and a stored energy has been measured by a diamagnetic loop. Figure 1 shows a typical time evolution of the stored energy.

After injection of a hydrogen ice pellet, the stored energy increases by about 2.5 kJ as a result of both the sustainment of the increased density and re-rise of electron temperature. Figure 2 shows an injected pellet-position dependence of an energy confinement time. It is found that the energy confinement times in the cases of on-axis injection and off-axis upward injection are better than that in the case of off-axis downward injection. Error bars mean the standard deviation of the shot average at the same injected position. The value z means a height from a plasma center. The bulk density before a pellet injection does not influence the dependence of energy confinement time on the injected pellet position.

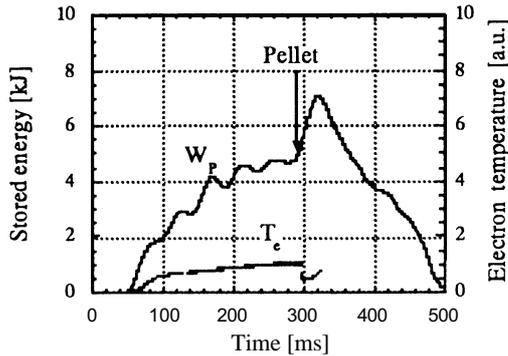


Figure 1. (a) Stored energy (W_p) by the diamagnetic loop and central electron temperature (T_e) by the ECE system for a typical ice pellet injection.

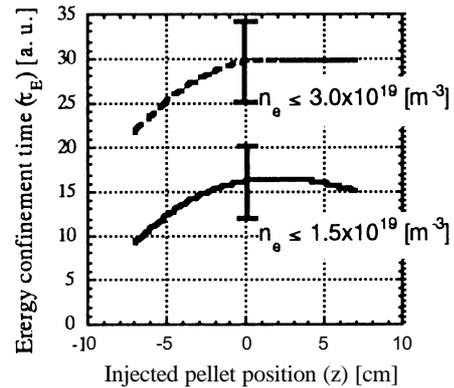


Figure 2. Injected pellet-position dependence of the energy confinement time. The value z means a height from a plasma center. The density n_e means the value before the injection.

Concerning the reason that energy confinement times in cases of on-axis and the off-axis upward injection are better than that in the case of off-axis downward injection, the following explanation may be considered.

In the cases of on-axis injection and off-axis upward injection, it has been observed that the ablation cloud poloidally rotates in the electron diamagnetic direction, and toroidally in the opposite to the plasma current direction [2]. In these cases magnetic fluctuations also poloidally propagates to the electron diamagnetic direction during the ablation, as shown in Fig. 3(a). By a heavy ion beam probe (HIBP) measurement, it has been shown that the direction of potential change is negative, and consequently the potential after the injection should be negative [3]. Only in the case of off-axis downward injection, it has been observed that the ablation cloud first rotates in the same direction with other cases, but at a certain time later it seems to decelerate and stay at the same location, or sometimes even flow back to the reverse direction, and that the direction of potential change measured by HIBP is positive. It is also shown that the magnetic fluctuations poloidally propagates to the ion diamagnetic direction during the ablation, as shown in Fig. 3(b).

The polarity difference between the injections into the upper and lower halves of the poloidal plasma cross-section may be interpreted as being due to the gradient-B drift of particles in the high density plasmas of the pellet cloud [4]. It may be considered that the

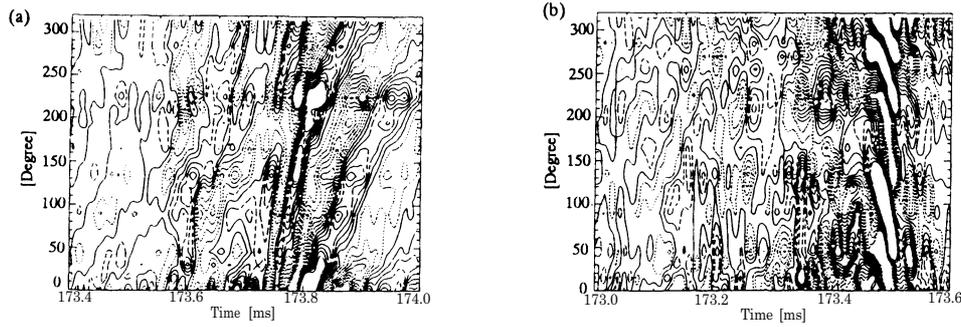


Figure 3. Time evolution of magnetic fluctuations obtained by the poloidal pick-up coil array, (a) in the case of off-axis upward injection, and (b) in the case of off-axis downward injection.

electron loss due to this toroidal drift in the case of off-axis downward injection will cause the deterioration of the energy confinement time. Figure 4 shows electron density profiles before and after a pellet injection in cases of the off-axis upward and downward injections. From the time evolution of electron density profiles obtained for various injection angles, it has become clear that the injected pellet position influences the transport as a particle diffusion and an inward pinch velocity [5]. Thus, the characteristics of both the pellet ablation and the energy confinement have close connection through a structure of the radial electric field, a density gradient and a temperature gradient.

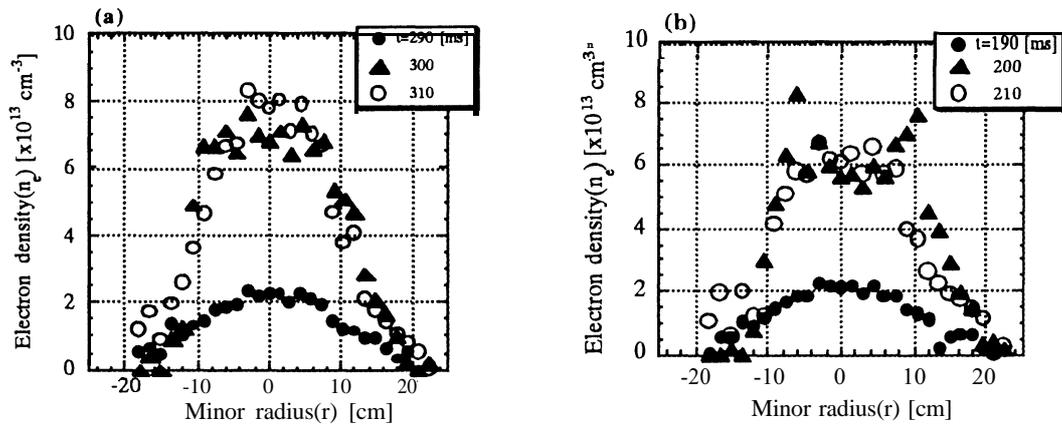


Figure 4. Electron density profiles before and after the pellet injection by the Thomson scattering method, (a) in the case of off-axis upward injection, and (b) in the case of off-axis downward injection.

3. Pellet ablation characteristics with NBI heating

In order to examine a macroscopic relation between ablation cloud behavior and plasma rotation, an ice pellet has been injected to the plasma at about 20 ms later after starting NBI heating. Figure 5 shows CCD images of the ablation light in the case that a pellet is injected at the position of about $z \sim +7$ cm, where B_T direction is counterclockwise and I_p direction is clockwise. In the case of off-axis pellet injection to the upward direction with NBI heating, it is found that the ablation cloud rotates in the same direction with the ohmic heating case. In this magnetic field configuration, it is concluded that the rotation direction of the ablation

cloud is the same with that of the plasma flow which was already studied by charge exchange recombination spectroscopy measurement [6]. The ablation cloud velocity is about one half of the plasma rotation velocity. Thus, the “tail” behavior may be caused by the effect of the plasma potential and the rotation within the torus plasma.

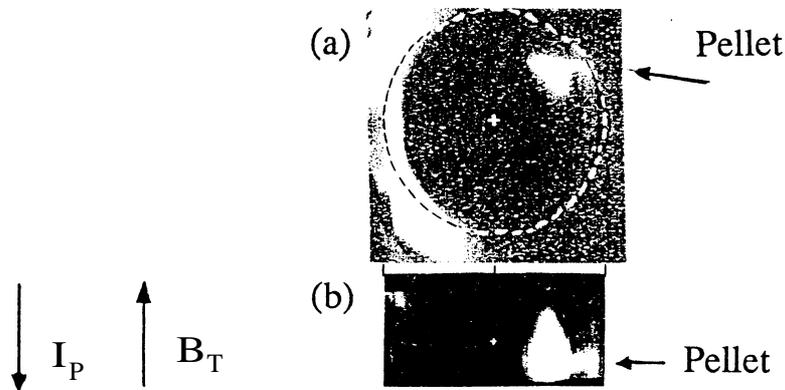


Figure 5. Images of the ablation cloud by CCD cameras in the case of pellet injection to $z \sim +7\text{cm}$ position of the NBI plasma. (a) A poloidal view from a tangential port, and (b) a toroidal view from a vertical port.

4. Summary

Pellet ablation characteristics has been investigated in the off-axis ice pellet injection with/without NBI heating in the JIPP T-IIU tokamak. In addition, the dependence of the energy confinement time of the plasma on the injected pellet position has been examined.

It is found that the energy confinement times in the cases of on-axis injection and off-axis upward injection are better than that in the case of off-axis downward injection. The bulk density before a pellet injection does not influence the dependence of energy confinement time on the injected pellet position. It may be considered that characteristics of both the pellet ablation and the energy confinement have close connection through the structure of a radial electric field, a density gradient and a temperature gradient.

It is found that the ablation cloud rotates to the same direction in the ohmically heated plasma in the case of off-axis upward injection to the NBI plasma. Thus, it is concluded that the “tail” behavior may be caused by the effect of the plasma potential and the rotation within the torus plasma.

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