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Preliminary Pellet Injection Experiment in the GAMMA 10 Tandem Mirror

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Abstract

In the GAMMA 10 tandem mirror, pellet injection experiments have been started as a solution for the density limit problem. This is the first pellet injection experiment in open systems. We describe the possibilities of confinement of pellet fueled particles. For that, we measure the number of end loss particles and compare them with pellet fueled ones in various conditions of confining potentials. The deterioration of confining potential with the pellet injection is a fundamental issue. The results show that the ion confining potential recover faster than central electron temperature due to the thermal barrier. We also consider the operating space for fueling method. It is demonstrated that the operating space for pellet injection exceeds gas fueled one on hot ion mode plasmas.

Keywords:

tandem mirror, pellet injection, density limit, confining potential

1. Introduction

Density limit problems have been observed in various tokamak devices, and pellet injection experiments have been carried out as one of means to solve this problem [1]. The density limit has also been observed in hot ion mode plasmas [2] of the GAMMA 10 tandem mirror with gas-puff fueling. Pellet injection experiments have been started as a solution for the problem. This is the first pellet injection experiment and has unique aspects in open systems. For example, tandem mirror machine is suitable for measurement of propagating pellet fueled particles along field lines.

It is concerned that pellet fueled particles immediately flow out along magnetic field lines in an open system. However, confinement of particles fueled by pellet injection is possible with confining potentials along the field lines in a tandem mirror.

The major issue with pellet injection is a deterioration of confining potential. One of the purposes of this article is to study the interactions between the plasma potential and the pellet injection.

In this paper, we show the possibilities of confinement of pellet fueled particles. For that, we measure the number of end loss particles and compare them with pellet fueled particles. We also consider the operating space in plasma parameters for the GAMMA 10 hot ion mode under gas fueling and pellet fueling.

2. Experimental Setup

2.1 The GAMMA 10 tandem mirror

The GAMMA 10 [3] tandem mirror consists of five magnetic mirror cells. One is a central cell which is the main confining region of a plasma. Others are

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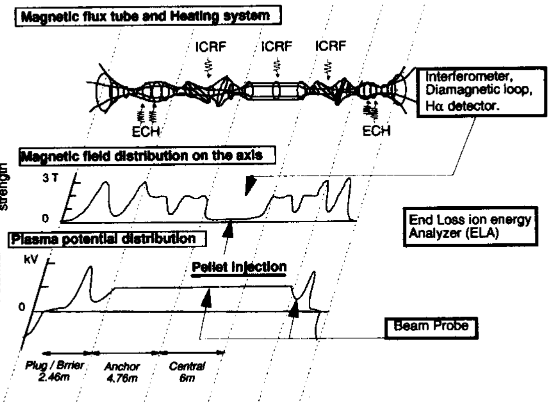

Fig. 1 Schematic of the GAMMA10.

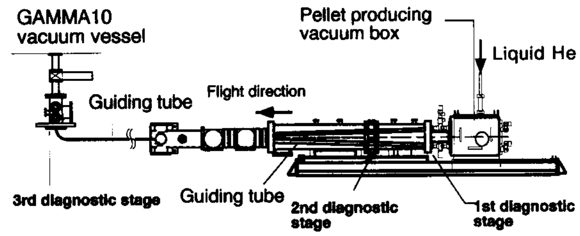

Fig. 2 Schematic of the pellet injector.

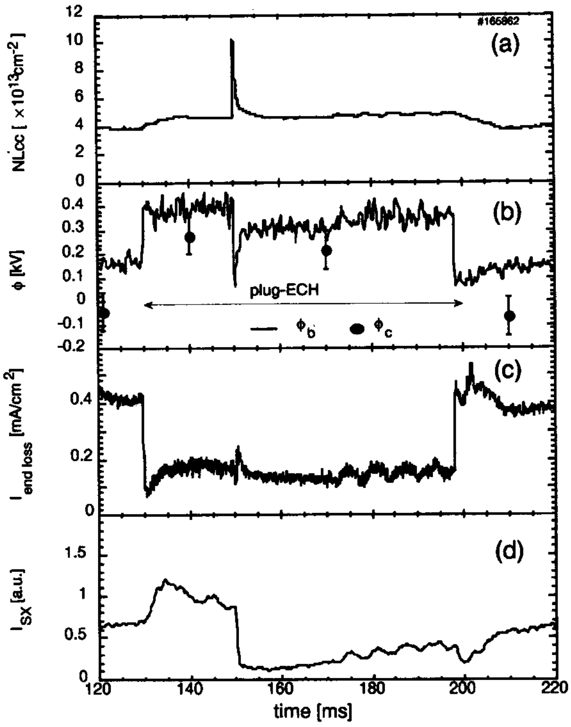

Fig. 3 The time evolution of the diagnostic signals of a typical hot ion mode plasma with a pellet injected at t = 150 ms. In due order, central cell line density (NL_{cc}), confining potentials (ϕ_b: a barrier depth, ϕ_c: ion confining potential), end loss ion current ($I_{end\ loss}$), the soft x-ray signal (I_{SX}).

minimum-B anchor cells and plug/barrier cells. The plasma is sustained by ICRF heating with gas puffing in the central cell. The confining potentials are formed by Electron Cyclotron Heating at plug/barrier cells.

The following instruments are mainly used for plasma diagnostics: Plasma densities are measured with microwave interferometers at several locations along the GAMMA 10 axial direction. End loss ion currents and ion energy spectra at the ends are measured with end loss ion energy analyzers (ELA). Plasma potentials in the central cell and in the barrier region are measured with heavy ion beam probes. The plasma potentials in the plug regions are determined by the energy analysis of end loss ions with ELA. The ion temperature is determined from the diamagnetic signal. Schematic of the GAMMA 10 and the diagnostic instruments of plasma are shown in Fig. 1.

2.2 Pellet injection system

The electron stored energy of the GAMMA 10 plasma is lower than that of other devices. Therefore, a submillimeter pellet injector is required for fueling. For this purpose, the ATF pellet injector made by the Oak Ridge National Laboratory [4] was modified and installed in the GAMMA10. The pellet injector is shown in Fig. 2. The injector is a pipe-gun type pneumatic pellet injector with eight barrels. The inner diameters of the barrels are 0.39, 0.58, 0.79 and 0.99 mm. The pellet injector is mounted at a central cell midplane through a 6m length of guiding tube.

3. Experimental Results

The experiments are carried out in the GAMMA 10 hot ion mode plasmas. The barrel which is used in these experiments is the one of inner diameter 0.79 mm. We compare the results with a confining potential and without it.

The temporal evolution of the diagnostic signals of a typical hot ion mode plasma with a pellet injected at t = 150 ms is shown in Fig. 3. The ion confining potential ϕ_c and the thermal barrier depth ϕ_b are formed with ECH at plug regions from 130 ms to 200 ms. At the time of pellet injection, the central cell line density rises up to 2 times of that before injection. Subsequent increase of end loss ion current is observed at both ends.

The thermal barrier depth ϕ_b reduces to almost 0 V. The soft x-ray signal, which correlates the central-cell electron temperature, sharply decreases immediately after the pellet injection. This implies that the electron stored energy is insufficient to the pellet ablation.

The spatial profiles of line integrated H_α emission in cases of gas fueling and pellet fueling are shown in Fig. 4. In the case of gas puffing, the tendency that particle source are slightly localized at the plasma periphery is observed. In the case of pellet injection, a fueling into plasma core is observed.

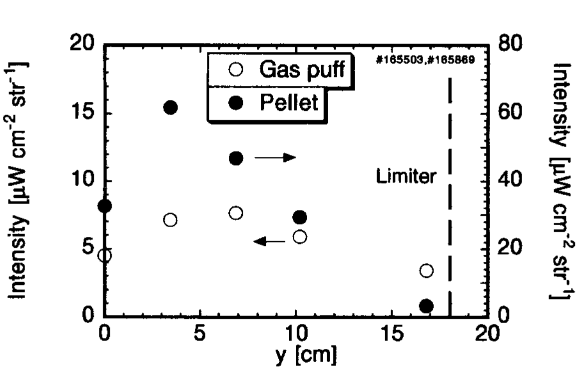

Fig. 4 The spatial profiles of line integrated H_α emission in the cases of gas fueling and pellet fueling.

4. Discussions

In Fig. 5, the number of end loss ions is plotted as a function of the number of pellet fueled particles in various conditions of potential confinement. In the case with confining potentials in both plug/barrier regions, the number of end-loss particles is estimated to be less than several percent of pellet fueled ones. In the case of no confining potential, on the other hand, the number of escaping particles increased to several tens percent. Under the condition that only one side potential is formed, the number of the opposite end-loss particles is increased to the same as the sum of the both ends loss with no confining potentials. Furthermore, it is observed that the number of flowing out particles decreases with the magnitude of the potential. Therefore, potential confinement of pellet fueled particles along field lines is clearly demonstrated.

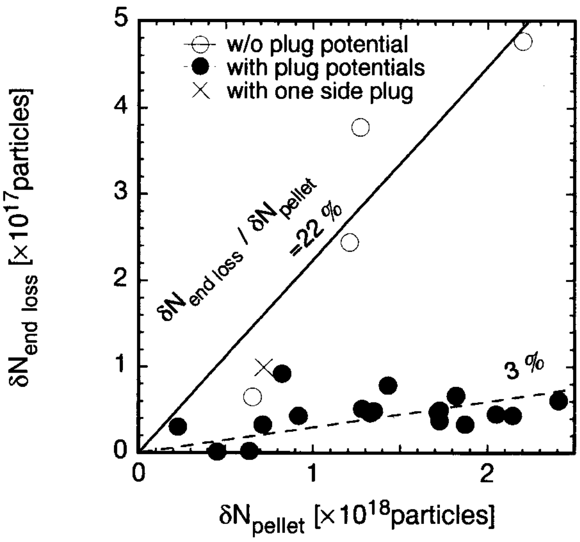

Fig. 5 Comparison between number of pellet fueled particles and number of end loss particles.

Fig. 6 shows the operating space of the GAMMA 10 hot ion mode. The vertical axis is average ion temperature and the horizontal axis is average density at the central region. We define average density as $\bar{n}_e^{cc} \equiv NL_{cc}/d$. Here, d is the diameter of plasma (usually 36 cm). In the case of pellet injection, we plot the time traces of the parameters from the start of ablation to 1ms after the time of maximum density. This time length seems to be comparable to the particle confinement time under these low electron temperature, since these experiments are carried out without the heating of central cell electron. The solid line in Fig. 6 represents the limit considering ion finite radius effects [5]. When the characteristic time of ion heating becomes smaller than electron drag time under the strong ion heating, ion larmor radius become large. Consequently such ions are lost by charge exchange reaction near the plasma edge, since the ion orbit get across the plasma boundary. From the particle balance between inflow of neutral gas and loss by charge exchange reaction for peripheral fueling, it is shown as

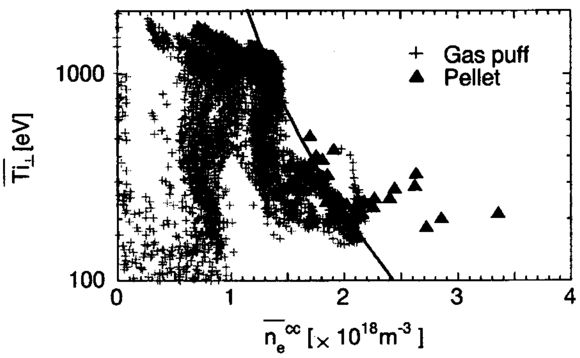

Fig. 6 Operating space for the GAMMA 10 hot ion mode plasmas.

$$\bar{n}_e^{cc} \approx \frac{v_0}{\langle \sigma v \rangle_{CX} r_p},$$

where v_0 is velocity of neutral gas, $<\sigma v>_{CX}$ and r_p are charge exchange rate coefficient and the plasma radius, respectively. $<\sigma v>_{CX}$ increases with ion temperature in this experimental condition. Thus, a operation with different fueling scheme may exceed the limit. From the result in Fig. 4, pellet injection is more effective fueling into a plasma core than gas puff fueling. The above discussion provides the reason why the plasma parameters in the condition of pellet fueling exceed the limit with gas puffing.

Sustaining the confining potential is an essential requirement for steady-state operation in tandem mirrors. At the time when a pellet is penetrating into a plasma , the plasma potential along field lines seemed to be flat. After the pellet injection, however, the ion confining potentials recover faster than the central cell electron temperature as shown in Fig. 3. The result implies that the thermal barrier, which insulate central cell and plug cell electron, is effective.

5. Conclusions

For steady state operation in the GAMMA 10 tandem mirror with pellet injection, we conclude the followings:

- Potential confinement of pellet fueled particles along field lines is demonstrated.
- It is clarified that the density obtained with the pellet fueling exceeds the limit with gas puffing due to fueling into the plasma core.
- After pellet fueling, the confining potentials recover faster than central electron temperature due to thermal barrier.
- In future work, we are going to study radial diffusion processes of the pellet fueled particles.

Acknowledgments

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Reference:

[1] G. Vlases *et al.*, Nucl. Fusion **27**, 351 (1987).

[2] T. Tamano, Phys. Plasmas **2**, 2321 (1995).

[3] K. Yatsu *et al.*, Nucl. Fusion **39**, 1707 (1999).

[4] A.L. Qualls *et al.*, *in Proceedings of the 13th Symposium on Fusion Engineering,* **2**, p.1244.

[5] T. Tamano, *in bulletin of 15th meeting of the Japan Society of Plasma Science and Nuclear Fusion Research* (in Japanese), (1998).