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Development of a Precise Size-Controllable Pellet Injector for the Detailed Studies of Ablation Phenomena

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Abstract

A new type pellet injector with precisely and continuously variable system of pellet size is being developed in order to study fundamental pellet ablation characteristics in detail. This has a unique mechanics and structure of producing the solid hydrogen in extremely low temperature region. It is possible to precisely adjust the length of the cylindrical pellet (Φ 1.0mm) from 0.5 to 3mm by using the special "length limiting rod".

1. Introduction

From the viewpoint of performance of nuclear fusion plasmas, pellet injection experiments have been actively carried out in many toroidal devices in the sense of the control of density profile, obtaining high density or improved confinement, and diagnostic purposes. In order to have a common measure of pellet ablation, the regression study has been performed as an international cooperation activity, obtaining “IPAD” (International Pellet Ablation Database) [1]. However, these are empirical ones, and the mechanism of pellet ablation still remains to be studied.

According to such database or calculations based on the typical pellet ablation model (such as, so-called the neutral gas shielding model), it is known that the penetration depth into plasma is always quite sensitive to the pellet size. Also, an effective or suitable range of the pellet size for a certain plasma is generally very narrow, and this range largely varies depending to each toroidal plasma size. These typical characteristics are seen in the calculation results for the JIPP T-IIU tokamak plasma (Fig.1) and for the TEXTOR plasma (Fig.2).

Thus, the precise controllability of the pellet size, especially the size controllability with continuously variable system, will be quite effective in order to carry out the detailed studies on pellet ablation and associated phenomena.

A pellet injector of new type with precisely and continuously controllable system of pellet size has started to be developed. This has a unique mechanics and structure of producing a frozen pellet in extremely low temperature region. The central part of the pellet injector with continuously size-variable system is given in Fig.3. In the device presently developed in this research, we will precisely adjust the length of the cylindrical pellet (Φ

1.0mm) from 0.5 to 3mm by using the special "length limiting rod".

2. Numerical analysis by Neutral-Gas-Shielding (NGS) model

In pellet injection, in order to obtain optimum injection parameter (size, speed and angle etc.), it is necessary to calculate ablation rate, namely particle deposition for ice pellet. In this study the numerical analysis has been carried out by using the Neutral-gas-shielding model in order to estimate the effect of pellet size on the penetration depth and plasma parameters. In this ablation model, pellet (neutral) particles ablate with heat flux in plasma to form the ablation cloud around the pellet. Then, the cloud shields the pellet from energy flux from plasma. The ablation rate (regression speed of the pellet surface) is expressed as

$$\dot{r}_{pel} \propto r_{pel}^{-2/3} n_{e\infty}^{1/3} T_{e\infty}^{1.64}$$

where r_{pel} is the pellet radius, $n_{e\infty}$ the electron density in plasma, and $T_{e\infty}$ the electron temperature in plasma. Figure 1(a) shows typical results of the pellet penetration depth into JIPP T-IIU plasma as a function of pellet velocity, where pellet size is varied from 0.1 to 1.0mm. Figure 1(b) shows the same as in Fig.1(a) into TEXTOR plasma, where pellet size is varied from 0.5 to 2.0 mm. As is seen, the penetration is quite sensitive to the pellet size, and also, an effective or suitable range of the pellet size for a certain plasma is generally very narrow, and this range largely varies depending on each toroidal plasma size and parameters.

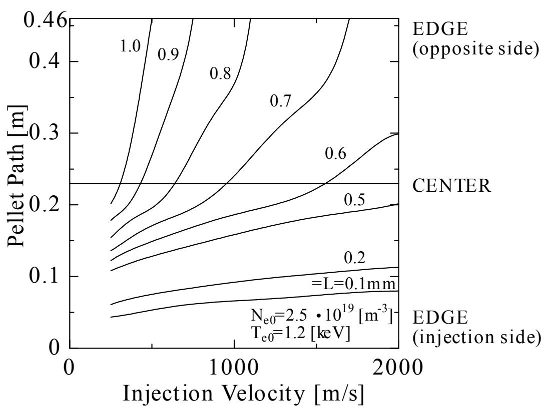

Fig 1(a). Typical results of the pellet penetration depth into JIPP T-IIU plasma as a function of the pellet velocity, where the pellet size is varied from 0.1 to 1.0mm

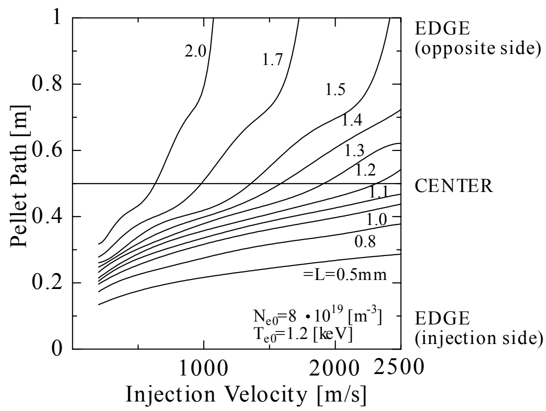

Fig 1(b). The same as in Fig.1(a) into TEXTOR, where the pellet size is varied from 0.5 to 2.0mm.

3. Development of the pellet injector with continuously size-controllable system

The central part of the continuously size-controllable pellet injection system being developed is shown in Fig.2(right), comparing with a conventional one (Fig.2(left)).

First series of experimental results have not shown expected ones; that is, there is no good agreement between values of set sizes and obtained ones (Fig.3(a) – (d)). After inventing a new procedure (Fig.4), quite precise and reproducible pellet control technique has been established (Fig.5). In the device presently developed in this research, it is possible to precisely adjust the length of the cylindrical pellet (Φ 1.0mm) from 0.5 to 3mm by using a special "length limiting rod".

The pellet injector system of this research is being developed in order to apply to the LHD research in the future. Therefore, the following issues are quite important to be established; (1) long term controlling, (2) remote operation, (3) total stability of the system. Thus, the cooling system has been changed from the liquid helium cooled type to the freezer type which might have caused an unfavorable temperature distribution. This problem is being solved now.

Fig 2. Central part of a conventional (left) and the continuously size-controllable pellet injection system (right).

4. Summary

A new type pellet injector with precisely and continuously variable system of pellet size (from 0.5 to 3mm) is being developed. The cooling system has been changed from the liquid helium cooled type to the freezer type. Further steps in the development will be done to optimize the cooling system, and to measure the pellet size by using a high speed camera system.

Reference

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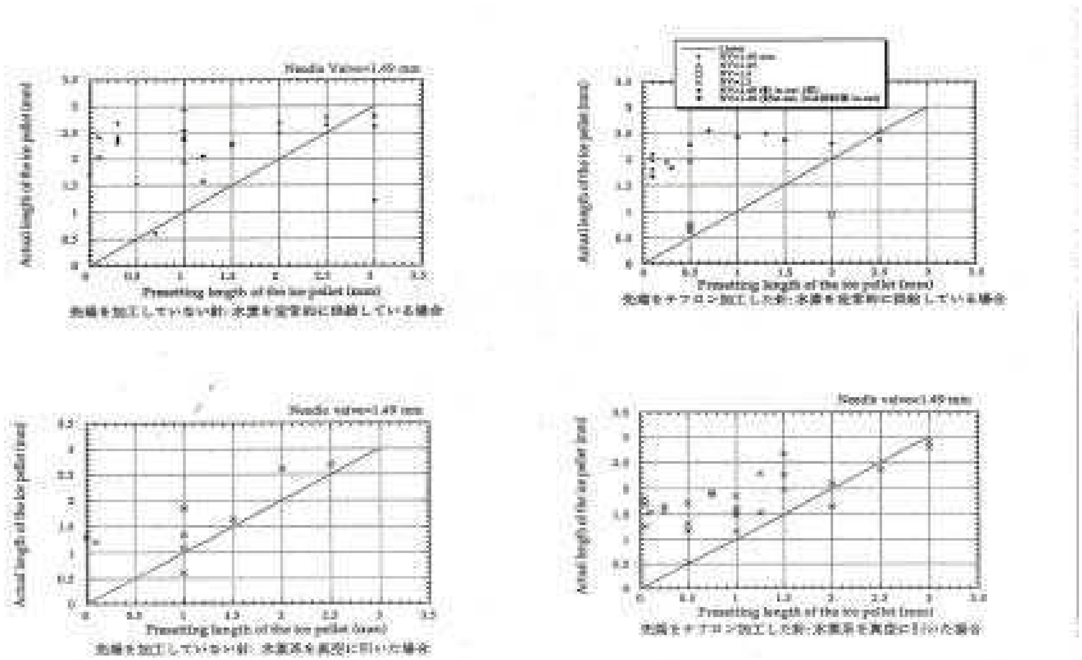

Fig. 3(a)left-top Typical result of pellet sizes obtained with hydrogen gas supply and conventional rod top.
Fig.3(c)left-bottom Typical result of pellet sizes obtained without hydrogen gas supply and conventional rod top.

Fig. 3(b)right-top Typical result of pellet sizes obtained with hydrogen gas supply and Teflon rod top.
Fig.3(d)right-bottom Typical result of pellet sizes obtained without hydrogen gas supply and Teflon rod top.

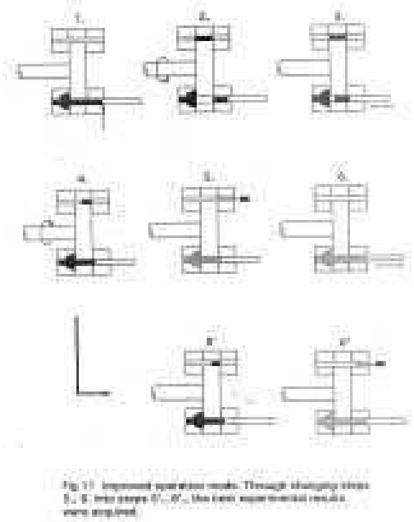

Fig. 4 Final procedure of pellet production ejection for precise and reproducible control of pellet size.

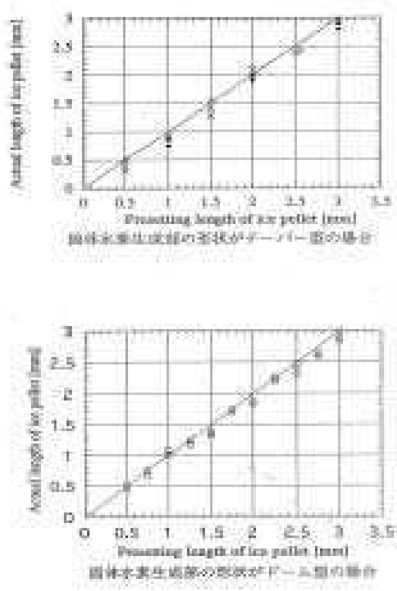

Fig. 5 Final results by the new procedure (as in Fig.4) with precise and reproducible production system.