§48. Three-Dimensional Observation of the Pellet Ablatant Using Stereography

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From the viewpoint of fueling efficiency, deep penetration of a pellet into a plasma is preferable. The penetration depth of the pellet into the plasma can be predicted by neutral gas shielding models, which is widely accepted theoretical pellet ablation models, and this model indicate that speeding up of the pellet launch velocity is practically only solution for the deeper penetration. Speeding up of the pellet velocity, however, is technologically difficult for the merit of the penetration depth ($\lambda \propto V_{pellet}^{1/3}$). As a different approach, we focus attention on a fast density redistribution of the pellet mass just after pellet injection [1]. Although the previous experiments indicated that the fast density redistribution contribute to a pellet particle loss, clarifying the phenomenon will provide a useful hint for improvement of the effective fueling.

We try to observe the pellet ablation and subsequent phenomena to investigate the fast migration of the pellet mass before dissipation into the plasma. Typically, the pellet ablation process occurs on the several 100 μs timescale and the spatial range of the ablatant expands from a few mm to the several meters while flying through the plasma with high speed, therefore three-dimensional observation with high time resolution is needed. In order to realize such a diagnostics, a fast camera, which is capable of taking an image of 100,000 frames per second, was employed for the observations. In addition, bifurcated imaging optical fiber, which can simultaneously focused two images onto a camera frame, is employed to observe a phenomenon from the different directions at exactly same moment, and we estimate three-dimensional position information by using stereography. The perspective projection, which exactly describes a pin-hole camera, is a nonlinear function. In order to avoid analyzing difficulty, the nonlinear function is linearized by using zero-order approximation of the Taylor expansion (i.e. weak perspective projection), and three-dimensional location can be described simply as follows if the line of sights are parallelistic.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} x_L B/d \\ y_L B/d \\ fB/d \end{bmatrix} \tag{1}$$

where $[X, Y, Z]$, $[x_{L(R)}, y_{L(R)}]$, B, d and f are real space coordinates, image coordinates, the distance between cameras, the parallax between two images and the focal length, respectively.

A stereo pair of the typical pellet ablatant images (negative image) is shown in fig. 1. Epipolar lines in the images are aligned with horizontal axis of the images. Three-dimensional positions of the pellet, which is surrounded with the pellet ablatant, are estimated by eq. (1) with the feature-based stereo matching which uses the intensity peak along the epipolar line to search the matching point. Fig. 2 shows temporal change of the pellet position in the major radius direction by means of stereography. The closed circle, solid line and dotted line denote the observed pellet position, the ablation light intensity (H_α) and the predicted pellet position from the injection timing and velocity (375 m/s), respectively. Close agreement between observed and predicted position is obtained. This result indicates that the pellet maintains the initial injection velocity during the pellet ablation process in the plasma.

The pellet ablatant expands along a magnetic field line, and that's formed of cigar-like shape (fig. 1). The penetration depth is also estimated by the pitch angle of the expanded ablatant because the confinement field of LHD is generated rigidly by external coils [2]. Several split plasmoids is observed in the vertical direction to the field line and the emission intensity is attenuated with bearing away. These observations suggest the discrete separation of the plasmoid from the ablatant, which surround the pellet substance, and subsequent dissipation of the plasmoid. The three-dimensional profile of the pellet ablatant is estimated by means of the area-based stereo matching in which the matching points are decided by correlation between the intensity patterns of the both images. The split plasmoid is observed at the outer side of the main ablatant in major radius, and it suggests the outward acceleration of the plasmoid. This result have the potential to explain the fast migration of the pellet mass.

[1] Sakamoto R. Yamada H., Annual report of NIFS, April 2000-March 2001 (2001) 15.
[2] Sakamoto R. et al., Nuclear Fusion, 44 (2004) 624.

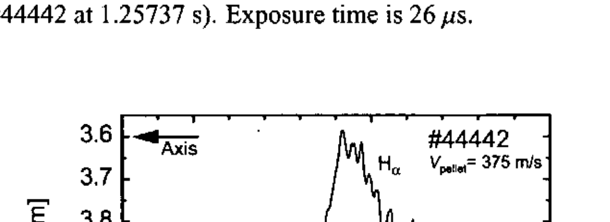

Fig. 1: Typical stereo pair of the pellet ablation images (#44442 at 1.25737 s). Exposure time is 26 μs.

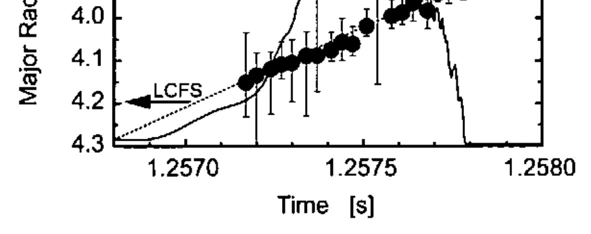

Fig. 2: Stereographically measured pellet position in the major radius (•).