*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-4.047 (2002)*

Studies of Three Dimensional Cloud Structure of Carbon Pellets Ablated in the W7-AS Plasma

V.M. Timokhin, B.V. Kuteev, V.Yu. Sergeev, V.A. Belopolsky, O.A. Bakhareva, R. Burhenn* and the W7-AS team

State Polytechnical University of St. Petersburg, 195251, Russia,
e-mail: timokhin@phtf.stu.neva.ru
**Max Planck Institut fur Plasmaphysik, EURATOM Association, Boltzmannstrasse 2, Garching, 85748 Germany, e-mail: burhenn@ipp.mpg.de*

Pellet injection is widely applied in fusion research for control and diagnostics of a high-temperature plasma discharge [1], [2]. Studying the drift flows of impurities in plasmas is one of the important diagnostic applications of pellet injection. Analysis of a pellet cloud structure can give additional information about such drifts [3]. Physical mechanisms of the drifts toward the low magnetic field side are discussed in Ref. [4]. The purpose of this work is to determine the drift direction of pellet clouds in the stellarator Wendelstein 7-AS (W7-AS) and to estimate the drift velocity on the basis of cloud structure. Tomographic methods have been applied to the clouds structure 3D-analysis [5]

In this work, results of high-speed photography for carbon pellet clouds in the W7-AS plasmas are presented. Details of the experiment are described in Ref. [6]. The ablation process was observed using several fast CCD cameras, a video camera and a wide-view fo-todetector. Interference filters with the central wavelength at 720 nm, which corresponds to a CII line, and with 10 nm bandpass were installed in front of these detectors. The cloud emission was registered from the lower port direction (at the angle of approximately 45° to the pellet trajectory) and from behind, along the pellet track direction The exposure time was 5 μs.

The photo database includes about 30 discharges. In snapshots, clouds have a shape of ellipsoids elongated in the direction of magnetic field lines. Depending on the local plasma parameters, the longitudinal and the transverse cloud sizes, measured at the level close to the background level (0.1 of the maximum value), are 0.8-3.0 cm and 0.5-1.5 cm respectively.

Let's discuss the cloud structure features on the basis of a typical shot #49982 (see Fig. 1) with the following plasma parameters: the inverse rotational transform $1/q=\iota=0.35$, the central electron temperature and density $T_e(0)=1.6$ keV, $n_e(0)=5.2\cdot10^{13}$ cm^{-3}, the ECRH power $P_{ECRH}=900$ kW. A spherical pellet with the diameter $d_p=0.4$ mm was injected with the velocity V_p=250 m/sec. The local undisturbed plasma parameters at the position of the pellet at the snapshot moment are T_e=230 eV, n_e=2.6·10^{13} cm^{-3}. The magnetic field direction in photos 1a and 1b is vertical. An arrow/cross shows the pellet velocity direction. Looking from the rear side the cloud looks symmetric (1a), while an asymmetry in the transverse direction is visible (1b) when looking from below.

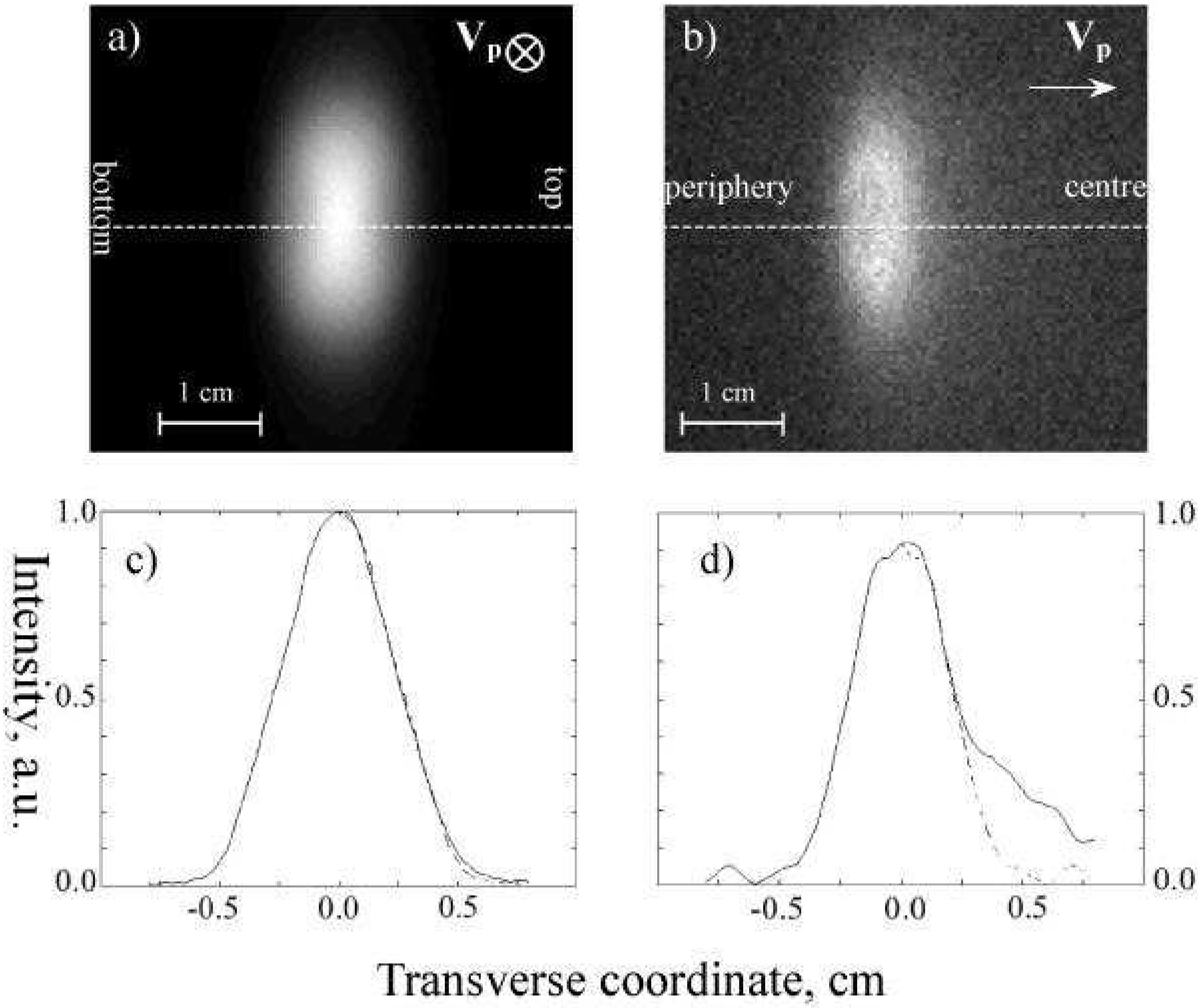

Fig. 1. a), b) The snapshots of the carbon pellet cloud in #49982. c), d) The corresponding intensity profiles in the central cross-section.

The cloud asymmetry is even more evident from the intensity profiles 1c, 1d (along dashed lines in 1a, 1b), where the dashed lines show the profile mirrored relative to the cloud center (). The intensity profile of the rear view (1c) has a small asymmetry, but it is not so noticeable as that of the view from below (1d). The intensity profile 1d is not so smooth as the profile 1ñ because the signal level in the snapshot 1à is higher than in the snapshot 1b. The discussed above structure is typical for the clouds with large linear sizes. The features of the registration system geometry cannot explain the radial asymmetry. This asymmetry indicates that the cloud plasma drifts toward the center of the stellarator.

The snapshots obtained by the CCD-cameras are normal projections of the cloud radiation on a plane perpendicular to the CCD viewing directions. In the approximation of the optically thin cloud, photos from two directions allow us to recover the 3D-intensity distribution using tomography methods [5].

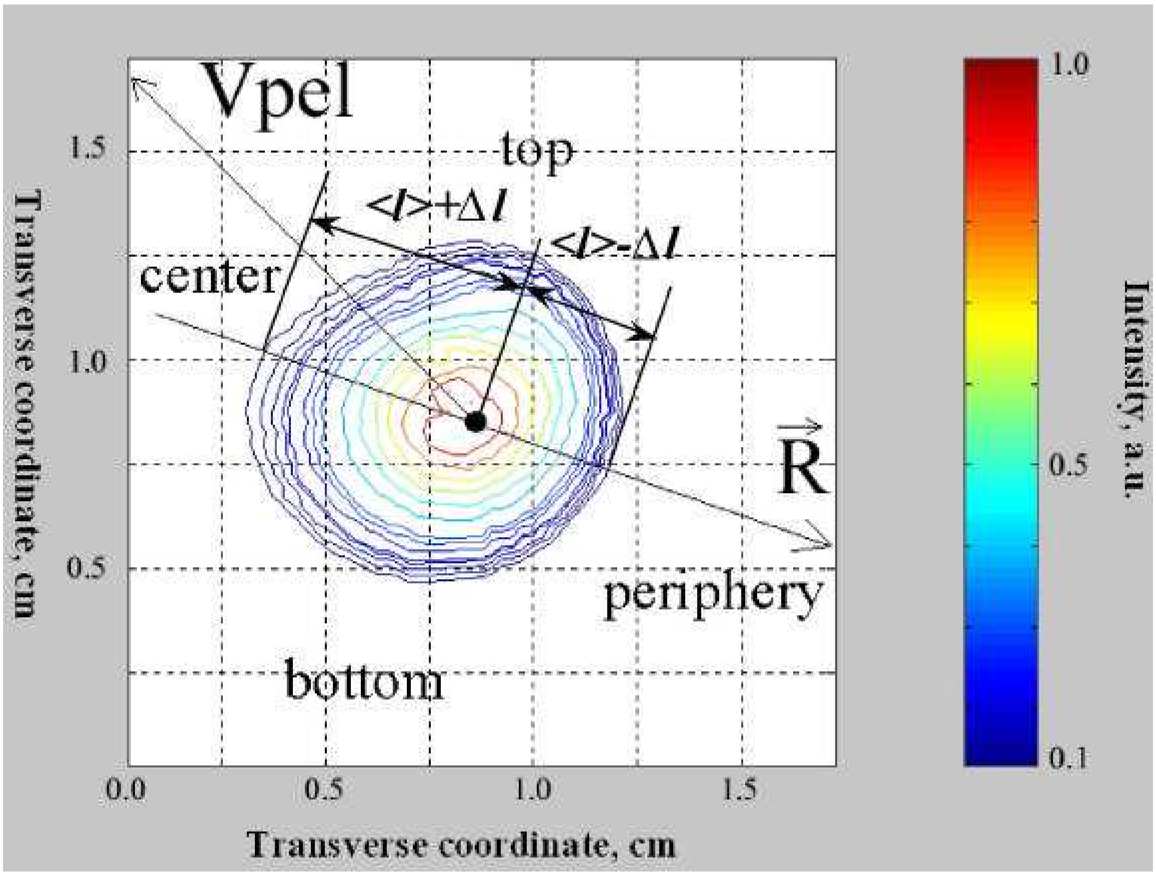

Fig. 2. An example of the restored intensity distribution for shot #49982 in the cross-section passing through the cloud center.

Since the cloud size is significantly less than the distance from the CCD cameras to the pellet, the light rays coming from the cloud to the cameras may be considered parallel. Without drifts, the flow of the particles in the transverse directions is isotropic. Therefore, we have supposed that for the local distribution restoration a system of distorted circles can be applied to the problem. In this case, the model distribution is as follows:

$$g(r,\theta) = g_0(r) + rg_1(r)\sin\theta + rg_2(r)\cos\theta, \quad (1)$$

where r and θ are the polar coordinates of the restored distribution, $g_0(r)$ describes the system of the isointensity lines as concentric circles, $g_1(r)$ and $g_2(r)$ are the projections of the perturbations on the axes of the Cartesian frame [5]. Following to the transformations described in Ref. [6], one can reduce the problem of the Radon transform to three Abel inversions for $g_0(r)$, $g_1(r)$ and $g_2(r)$.

Fig. 2 shows an example of the restored light intensity in the cross-section, which passes across the magnetic field through the center of the cloud. The magnetic field is normal to the figure plane. Arrows indicate the directions of the pellet velocity and of the machine major radius.

The restored distribution reveals the spatial asymmetry of the cloud, which is particularly emphasized for isolines with low intensities (~10% of the maximum). The cloud is asymmetric along the major radius direction and is elongated toward the high magnetic field side. The azimuthal structure of the cloud weakly varies along the magnetic field direction. The obtained intensity distribution allows us to estimate the drift velocity using the following formula:

$$V_{dr} \sim \frac{\Delta l}{\langle l \rangle} \frac{\langle l \rangle}{\tau_{ion}}, \tag{2}$$

where $\langle l \rangle \cong 0.14$ cm is the average cloud size across the magnetic field, which is calculated from intensity decay length, $\Delta l \cong 0.06$ cm is the difference between cloud sizes in the directions against and along the major radius. The ratio $\langle l \rangle / \tau_{ion}$ determines the cloud expansion velocity across the magnetic field, $\tau_{ion} \cong 2$ μsec is the ionization time of carbon atoms to the charge state C^{2+}, calculated using the results of Ref. [8]. Thus from equation (2) gives a value for V_{dr} of ~300 m/s. The direction of the drift observed on W7-AS differs from that obtained in the experiments on the ASDEX Upgrade tokamak [9], where the hydrogen pellet cloud plasma drifted towards the low field side direction. Physical mechanisms of the discovered drift in direction of the high field side remain unclear at the moment.

References

[1] B.V .Kuteev et al.,Fusion technology 26, 1994, pp. 938-944.

[2] B.V .Kuteev, Technical Physics J., 1999, Vol.69, No.9, pp. 63-67.

[3] S.M. Egorov et al, Tech. Phys. Lett., 1987, Vol.13, No.9, pp. 569-573.

[4] V Rozhansky et. al., Plasma Phys. Control. Fusion, 1995, No.37, pp. 399-414.

[5] M. Freemen, S. Katz, J. Opt.Soc.Amer., 1963, Vol.53, No.10, pp. 1172-1179.

[6] L. Ledl, R. Burhenn, V. Sergeev et al., EPS, 1999, Vol.23J, pp. 1477-1480.

[7] B.V .Kuteev, M.V. Ovsishcher, EPS 1991, Vol.4, pp. 241-244.

[8] K.L. Bell et.al., J. Phys. Chem. Ref. Data, 1983, No.12, p.891.

[9] H.W Muller et al., Phys. Rev. Lett.,1999, Vol. 83, No.11, p.2199.