§5. Explanation of the Potential Change Observed during Ablation of Pellet Injection (Theory)

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The changes of the potential with off-axis injections can be explained in the following manner. The high-density blob produced by downward pellet injection stays for a short duration in the lower portion of the magnetic surface while expanding toroidally. Because of the gradient-B drifts (curvature drifts) of ions and electrons in the high-density blob, charge separation occurs vertically; in this case, radially. It is impossible for high temperature electrons to compensate the charge separation, since it occurs radially, that is, across the different magnetic surfaces. It should be noted that the potential tends to be constant on the magnetic surface (surface quantity), because the potential perturbation propagates very rapidly. Since the measured potential is an integral of the electric field from the vacuum vessel to the sample volume, it is sensitive to the generation of the radial electric field outside the magnetic surface on which the sample volume is located. It is insensitive to the radial electric field inside the magnetic surface of the sample volume. This explains why in the experiment we observe the large potential changes even though the pellet does not penetrate to the magnetic surface of the sample volume.

The order of magnitude of this potential may be estimated by the following consideration. Let us assume that the pellet is deposited at a minor radius of r_{pl} and at a poloidal angle of θ_{pl}. The pellet cloud has a depth of L_{pl} across the magnetic surface and an area of S_{pl} along the magnetic surface. It has an averaged plasma density of $n_{e,pellet}$, and an average temperature of T_{pellet}. The amount of charge accumulation dQ/dt, across the magnetic surfaces is given by $dQ/dt = j_{drift} \cdot S_{pl} \cdot \sin(\theta_p)$, where j_{drift} is the vertical current induced by the gradient-B drift of the pellet cloud. j_{drift} can be expressed as $j_{drift} = n_{e,pellet} \cdot 2kT_{pellet}/(m_e \cdot R_{pl} \cdot \omega_{ce})$, where R_{pl} is the major radius of the dominant ablation point in the plasma. We model the potential formation as charging by j_{drift} a parallel plate capacitor with an area of magnetic surface and a plate separation given by Lpl. The capacitance is $C_p = \varepsilon_o \cdot \varepsilon_p (2\pi R_p\, 2\pi r_{pl}) / L_{pl}$, where ε_p is the plasma dielectric constant. Since ε_p is expressed by $\varepsilon_p = 1 + (\omega_{pi}/\omega_{ci})^2$, it is proportional to the plasma density. The capacitance is then dominated by the contribution from the pellet cloud for the case that the number of total deposited particles is higher than that of the original particles located between the magnetic surfaces which are separated by L_{pl}. This case is experimentally supported by the fact that the fast ECE temperature drops to less than half at our pellet injection. In this case $C_p = \varepsilon_o \cdot \varepsilon_p \cdot S_{pl} / L_{pl}$. The rate of potential change at the magnetic surface inside the ablation region is $d\Phi_p/dt = (dQ/dt) / C_p$ and can be simply described by

$$\frac{d\Phi_p}{dt} \cong \frac{2L_{pl}}{R_{pl}} \frac{kT_{pellet}}{e} \omega_{ci} \sin(\theta_p). \quad (1)$$

The gradient-B drift can explain the polarity of the potential change for off-axis injection through the dependence on sin(θp). Table 1 shows the various parameters associated with the pellet injections for the cases in Fig. 2 in the experiment. We measured the thickness of the ablation cloud L_{pl} by the rapid decrease of multichannel ECE signals during pellet injection, assuming that the electron energy on the given magnetic surface remains nearly constant before radial heat diffusion becomes dominant. Many previous works by several authors both theoretical and experimental, have determined that the temperature of the pellet cloud is a few eV. If we assume that the temperature of pellet cloud is 2 eV, the predicted values of the rate of the potential change are about one order of magnitude larger than the observed values, as shown in Table 1. This difference may be explained by several factors. One is the fact that the very high density part of the plasma blob is so collisional that it may not effectively contribute to the charge separation due to the gradient B drift. The high temperature portion of the plasma blob tends to become rapidly uniform on the magnetic surface and does not effectively contribute to the formation of the potential.

Parameters \ Shot Number	#70501	#70430	#70506
Injection angle [Degree]	- 3.0	0	+ 4.0
L_{pl} [cm]	6	6	6
r_{pl} [cm]	7.4	10.0	9.8
θ_{pl} [Degree]	- 66.0	0	+ 66.0
dΦ/dt (Theory) [V/Sec]	6.5×10^7	0	-6.4×10^7
dΦ/dt (Observed) [V/Sec]	5×10^6	0	-3.9×10^6

Table 1. Injection parameters of the hydrogen pellets and comparison of the rate of potential changes (experiment and theory).