

Atomic process effect on poloidal CXRS measurement in the JT-60U

tokamak

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Abstract Modifications with considering finite lifetime of excited ions and sightline direction show that measured poloidal velocity is overestimated and ion temperature is underestimated by the poloidal charge exchange recombination spectroscopy (CXRS) measurement, showing agreements with the simulations on CXRS. In the internal transport barrier (ITB) case, a poloidal rotation velocity maximum is located near the ITB foot, whereas, the negative maximum is nearly located at the edge transport barrier (ETB) shoulder in this case. The radial electric field profile is affected greatly by poloidal rotation.

1. Introduction In JT-60U, poloidal plasma rotation velocity is diagnosed by CXRS[1] by means of analyzing the impurity ion (C^{5+}) line emission profile. However, the measured line emission by charge exchange reaction (CXR)[2] distorts the real velocity distribution of the fully ionized ion (C^{6+}) because of the effects [3,4]: the finite lifetime of excited states, charge-exchange cross section, change of ion gyro-frequency, neutral beam non-uniformity and its observation direction. As a consequence, it leads to a pseudo velocity not associated with real rotation velocity. Therefore, it is necessary to evaluate the measured line emission with considering the above effects, hence modifying ion temperature, rotation velocity.

2. Principle and modification method We define an orthogonal coordinate of x, y and z, so that v_x , v_y , v_z are along the direction of radial, sightline and magnetic field, respectively. In a tokamak geometry, there is a tilted angle $\pi/2-\theta$ between the poloidal direction and the sightline direction (v_y), where θ is the angle between poloidal direction and axis z (magnetic field direction). The intensity profile along poloidal direction ($v_p = v_y \sin\theta$) is approximately

$$I_p(C^{6+}) \propto \exp\left\{-\frac{M[v_p - (v_{EXB} + v_{dia} + v_T) \sin\theta]^2}{2T}\right\} = \exp\left\{-\frac{M[v_p - v_0]^2}{2T}\right\} \exp\left\{\frac{Mv_T[v_p - v_0]}{T}\right\} \quad (1),$$

from which a shifted velocity along the poloidal direction can be obtained by fitting the line profile $\exp\{-M[v_p - v_0]^2 / (2T)\}$, where $v_0 = (v_{EXB} + v_{dia}) \sin\theta$ represents the drifting velocity

along the poloidal direction, v_{EXB} is the EXB drift velocity, v_{dia} the diamagnetic drift, and v_T the velocity caused by temperature gradient, Ω the gyro-frequency of the ground ions.

Characterizing a direction of the line of sight by the polar coordinate (θ_0, ψ_0) with a polar angle θ_0 measured from the axis z and an azimuthal angle ψ_0 (observation angle) measured from the axis x , the presence of ψ_0 suggests that the sightline is not along the poloidal direction, but in the direction of v_{obs} ($v_{obs} = v_p \sin \psi_0 + v_x \cos \psi_0$), so the measured shift is not pure poloidal rotation velocity. A line profile in observation direction is obtained by integrating the distribution function (f) of the excited ions (C^{5+}) [4] formed by CXRS

$$I(obs) \propto \int f(v) d\sigma \propto \exp\left\{-M(v_{obs} - v_{EXB} \sin \theta_0 \sin \psi_0 - u_1 - u_2 - u_3 - u_4)^2 / (2T)\right\}$$

$$\propto A \times \exp\left\{-M(v_p \sin \psi_0 - v_{measure})^2 / (2T)\right\}, \quad (2)$$

where, $v_{measure}$ is the raw shifted velocity measured by CXRS, $A = \exp\left\{-M(v_x^2 \cos^2 \psi_0 - 2 \times v_x \cos \psi_0 \times (v_p \sin \psi_0 - v_{measure})) / (2T)\right\}$, u_1, u_2, u_3 and u_4 are defined in ref. 4. Equation (2) can be written into the following form by neglecting the second-order smallness $Mv_1^2 / (2T)$ and $Mv_0v_1 / (2T)$,

$$I(obs) \propto A \exp\left\{-M(v_p - v_0)^2 / (2T / \sin^2 \psi_0)\right\} \exp\left\{Mv_p v_1 / (T / \sin^2 \psi_0)\right\} \quad (3), \quad \text{where}$$

$$v_0 = (v_{EXB} + v_{dia}) \sin \theta_0, \quad v_1 = (u_1' + u_2 + u_3 + u_4) / \sin \psi_0, \quad u_1' = u_1 - v_{dia} \sin \theta_0 \sin \psi_0,$$

$$u_2' = u_2 - v_T \sin \theta_0 \sin \psi_0. \quad \text{Then, } \exp\left\{-\frac{M(v_p - v_0)^2}{2T / \sin^2 \psi_0}\right\} \propto \int I(obs) dv_{obs} / \exp\left\{\frac{Mv_p v_1}{T / \sin^2 \psi_0}\right\} / (\int Adv_{obs}) \quad (4).$$

The left hand side term is just corresponding to impurity ion (C^{6+}) line profile obtained in Eq. (1), from which a modified shifted velocity and temperature can be induced.

3. Modification results For a JT-60U plasma (shot 36479 ($t = 6.0s$)) [1], assuming a Maxwellian velocity distribution with measured $T_i = 7.601keV$ and $v_{measure} = -40206m/s$ by

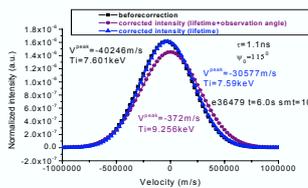


Fig. 1 Normalized intensity profiles before and after modification

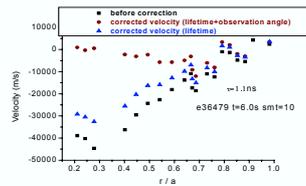


Fig. 2 Poloidal rotation velocity profiles before and after modification

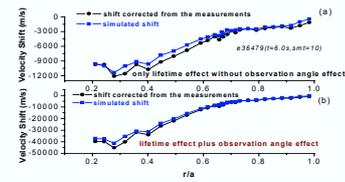


Fig. 3 Comparison of velocity profiles between modifications and simulations

poloidal CXRS with an observation angle $\psi_0=115^\circ$, modified normalized intensity profiles are displayed in Fig.1. Results show that the spectrum changes very little without considering the sightline effect (i.e., $\psi_0=90^\circ$), the spectrum, ion temperature and rotation velocity are modified greatly when the observation angle effect is taken into account, indicating poloidal velocity is overestimated and ion temperature is underestimated by the measurement. The poloidal rotation velocity profiles before and after modification (Fig.2) show that the effect of observation angle on rotation velocity is prominent in the core region, whereas in the edge region this effect is small. The profiles of pseudo velocity, defined as the difference between original measurement and the modification ($\Delta v = v_{\text{measure}} - v_{\text{correction}}$), are compared with the velocity shift not associated with the poloidal rotation simulated in the way described in ref. 5, indicating two results are almost in agreement (Fig.3).

For a discharge of 36486 ($t=5.9s$) [6], a modified velocity profile is displayed in Fig.4, in which also shown are the original measurements and the neoclassical velocities. It is shown that there exists a large discrepancy between the modified result and the neoclassical values, especially in the ITB region. Also, it is observed that a negative maximum is located near the foot of the internal transport barrier (ITB).

Radial electric field (E_r) profiles (Fig. 5) show that E_r evaluated with the modified velocity is affected greatly by the poloidal rotation term, but its peak position is almost consistent with that calculated with the neoclassical values. It seems that the modification increases E_r shear because the maximum of poloidal rotation term is located near the ITB foot, thus, deepening the E_r well.

The modified velocity profiles with ITB (36401 and 36486) and without ITB (37749)[7] are shown in Fig.6, from which we see that for the ITB case, the negative

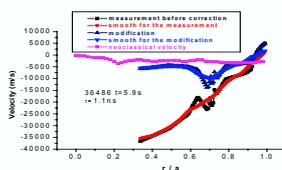


Fig.4 Velocity comparison

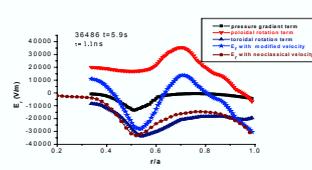


Fig. 5 E_r profiles

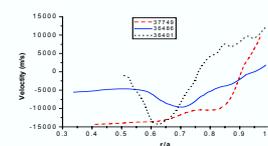


Fig. 6 Modified poloidal velocity profiles

maximum of the poloidal velocity moves with the movement of the ITB foot. Whereas for the case without ITB, the poloidal velocity has no obvious reduction as seen in the ITB case.

For the edge transport barrier (ETB) case (shot 24573 $t=6.35s$)[8], Fig. 7 (a) shows the edge pressure ($n_e \times T_i$) profile, indicating an existence of H-mode pedestal near $r/a \sim 0.9$. The corresponding poloidal velocity profile shown in Fig. 7 (b) shows that the negative maximum of velocity is nearly located at the ETB shoulder. Three E_r components (Fig. 8), E_{rPol} , $E_{rGra} + E_{rTor}$, and $E_{rGra} + E_{rTor} + E_{rPol}$, show that E_r profile is greatly modified by E_{rPol} , especially in transport barrier region the E_r shear is increased dramatically by the poloidal rotation because of the larger localized poloidal velocity near the ETB shoulder.

5. Conclusions Modifications with considering atomic process show that poloidal velocity is overestimated and ion

temperature is underestimated by the poloidal CXRS measurement in JT-60U. The observation angle effect on rotation velocity is prominent in the core region, whereas in the edge region the observation angle effect is small. In the ITB case, a poloidal rotation velocity maximum is located near the ITB foot, whereas in the ETB case, the negative maximum of velocity is nearly located at the ETB shoulder. E_r evaluated with the modified velocity is greatly affected by the poloidal rotation term near the transport barrier.

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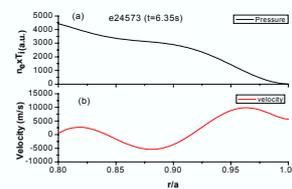


Fig. 7 Pressure and poloidal velocity profile

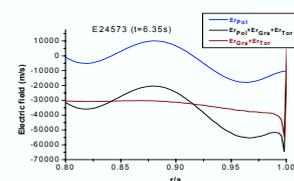


Fig. 8 E_r components

E_{rPol} : poloidal rotation term

E_{rTor} : toroidal rotation term

E_{rGra} : Pressure gradient term