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To the question of discrepancy between measured poloidal rotation velocity V_p in a tokamak plasma by corpuscular and CXRS methods and its predictions under the collisionless neo-classical theory.

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Tokamak experiments have shown that the poloidal rotation velocity of the plasma, $\mathbf{V_p}$, measured by CXRS [1] and corpuscular CX [2] methods, during the internal transport barrier (ITB) zone formation, significantly differs from predictions of the poloidal rotation following from the neo-classical theory, $\mathbf{V_{p,n\text{-}c}}$. The poloidal rotation velocity in a tokamak is usually determined using Hirshman and Sigmar approach through the flux-surface average moment [3]. It gives $\mathbf{V_{p,n\text{-}c}} \sim dT_i/dr$ for background plasma ions (the term proportional dT_i/dr is main one for an impurity poloidal rotation velocity, too). Experimental $\mathbf{V_p}$ measurements are taken at a specific point on a magnetic surface. However, Hirshman and Sigmar approach doesn't give an explicit $\mathbf{V_p}$ expression for this case. In this paper, an explanation of discrepancy between the measurement $\mathbf{V_{p,meas}}$ and theoretical $\mathbf{V_{p,n\text{-}c}}$ is proposed. This explanation is based on the evaluation of the role of the actual measurement point location on "banana" trajectories.

Consider an equilibrium shifted in poloidal, $\mathbf{V_{p0}}$, and toroidal, $\mathbf{V_{t0}}$, directions Maxwell ion function distribution F_M existing in each point of a magnetic surface at some initial moment. Assume that we have an ideal device for the measurement of ion distribution functions (such as a neutral partical analyzer NPA for charge-exchange flux measurement) along the view sight of this device. The set-up for such measurements of $\mathbf{V_p}$ is shown on Fig.1. Assuming that we measure an ion distribution function at the point IP1 (or IP2) on the magnetic surface between the magnetic surfaces M1 and M2. Measurement by CXA2 is equivalent to those taken by CXA3. Let ions have made several excursions along drift trajectories before the moment of measurement, and suppose we measure $\mathbf{V_{p,meas}}$ for the collisionless case. One can make use of the approach of Refs.[4,5], so as to show that ions under measurement should have $V_{II}/V_\perp = Bt/Bp$ for CXA1 and $V_{II}/V_\perp = -Bt/Bp$ for CXA2, where V_{II} ($V_\perp$) is the parallel (perpendicular) component of the ion velocity in respect to magnetic stress line, Bt (Bp) is the toroidal (poloidal) component of tokamak magnetic field. It means that the CXA1 observes ions at point IP1 with an effective temperature of M1 magnetic surface, while CXA2 (or CXA3) measures ions with the temperature of M2 magnetic surface.

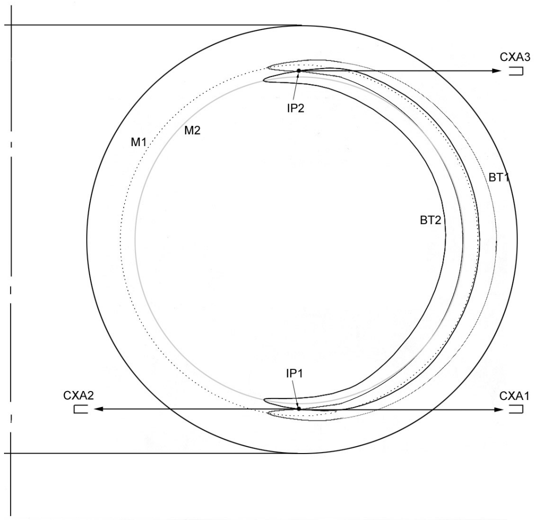

FIG.1. Experimental set-up for measurements of poloidal rotation velocity. Shown is the "banana" trajectory, BT1, which belongs to the magnetic surface M1 and the "banana" trajectory, BT2, on M2 surface. CXA1, CXA2, CXA3 are NPAs for ion distribution function measurements at points IP1 (and/or IP2). Charge-exchange at IP1 generates neutrals fluxes to CXA1 and CXA2 carrying information about ion distribution function at this point.

The distance Δ between the IP1 and M1 (and M2) is $\Delta \approx \frac{V_\perp}{\Omega}(1 \pm \frac{B_t}{B_p}\frac{V_{t0}}{V_\perp})$, where Ω is an ion Larmor frequency. It shows that the measured ion distribution function at IP1 differs from the initial ion distribution function at IP1. We can say about some shift of the measured ion distribution function as compared to the initial ion distribution function in IP1. By expanding F_M in Δ, which is small enough, if compared to minor radius at IP1, it is possible to calculate such extra shift in terms of the poloidal rotation velocity, which is:

$$V_{p,meas} \approx \pm V_{p0} \pm \frac{c}{ZeB_t}\left(\frac{T_i}{n_i}\frac{dn_i}{dr} + \frac{E}{T_i}\frac{dT_i}{dr} - \frac{3}{2}\frac{dT_i}{dr}\right)\cdot\left(1 \pm \frac{B_t}{B_p}\frac{V_{t0}}{\sqrt{2E/M}}\right), \qquad (1)$$

where E is the measured energy of the ions, "+" refers to CXA1 NPA and "-" to CXA2 analyzer. We did not take into account the difference between $\mathbf{V_{p0}}$ at M1 and M2. Averaging for the initial F_M at IP1, we obtain:

$$V_{p,meas} \approx \pm V_{p0} \pm \frac{c}{ZeB_t}\frac{T_i}{n_i}\frac{dn_i}{dr}\cdot\left(1 \pm \frac{B_t}{B_p}\frac{V_{t0}}{V_T}\right), \qquad (2)$$

where V_T is ion thermal velocity. It is clear that there can be experimental conditions under which the term proportional to $\frac{dn}{dr}$ determines the measured $V_{p,meas}$.

There can exist a very interesting condition of the experiment that may verify our proposal. Such a scenario is presented in Fig.2. Measured ions at IP for this case are related to different barely passing trajectories. It means that the $\frac{dn}{dr}$ term described above has the sign opposite to one resulting from the schematic in Fig.1, and $V_{p,meas}$:

$$V_{p,meas} \approx \pm V_{p0} \mp q \cdot \sqrt{\frac{R}{r}} \frac{c}{ZeB_t} \frac{T_i}{n_i} \frac{dn_i}{dr} \cdot (1 \pm \frac{B_t}{B_p} \frac{V_{t0}}{V_T}) \qquad (3)$$

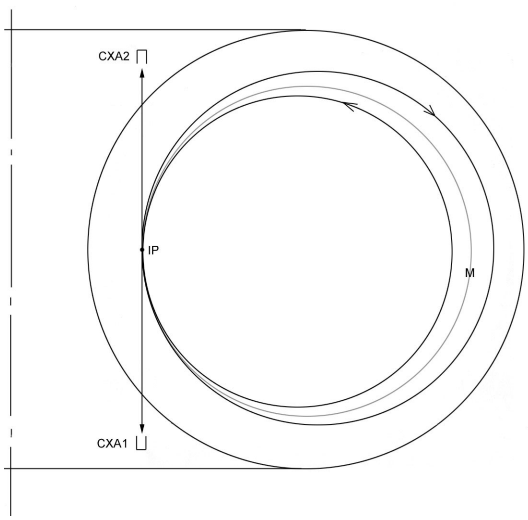

FIG.2. Experimental set-up for the poloidal rotation velocity measurements at the point IP.

It can be shown that the additional $\frac{dn}{dr}$ term is decreased after averaging along the poloidal direction (see Eqs. (1) and (2)). It means that the averaged $V_{p,meas}$ is close to $\mathbf{V_{p0}}$.

The experimental CXRS based method is different from the corpuscular NPA. Collected photons carry information about the velocity shift in the ion distribution function at the point of measurement. They are radiated by ions, which move in arbitrary directions relative to the observation view line, such as for example, a line from IP1 to CXRS detector. We show a schematic contour of an ion distribution function in the horizontal plane on Fig.3. Only $\frac{dn}{dr}$ term introduced above is included. Equilibrium distribution function F_M would have circular contour whose area would be equal to one of contours in

Fig.3. The case shown above in Fig.1 corresponds to the viewline V_2-V_1-V_p. One can see from Fig.3 that there is an additional $\frac{dn}{dr}$ shift of ion distribution function in the case of poloidal rotation velocity measurement by CXRS method. This shift is expected to be close to $V_{p,meas}$ in eq.(2).

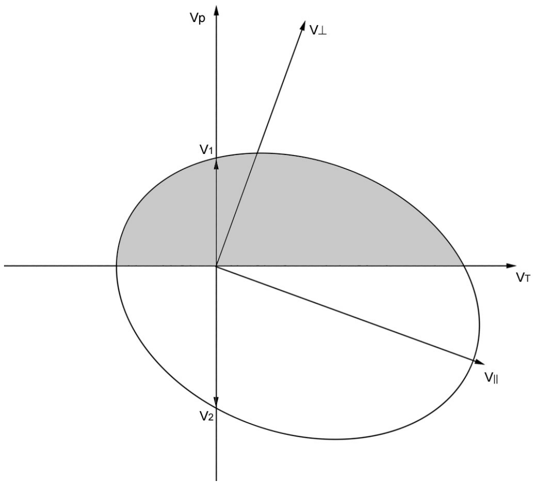

FIG.3. The contour of ion distribution function in the horizontal plane.

Conclusion.

We considered a possible approach to the interpretation of a measured poloidal rotation velocity shift of the ion distribution function, eq. (2) and eq. (3). The $\frac{dn}{dr}$ term can explain the observed discrepancies between measured poloidal rotation velocities and theoretical predictions. There are still problems, such as, for example, a relationship of Hirshman and Sigmar approach to $V_{p,meas}$ in Eqs.(2,3), etc.

We can propose a very simple experimental test for checking the described approach. If one measures $V_{p,meas}$ an the point IP1, as shown in Fig.1, and at IP, as in Fig.2, on the same magnetic surface and in a discharge with strong poloidal rotation velocity, one can expect large discrepancy of measured $V_{p,meas}$ for these two cases (up to values with opposite signs).

[1]R.J.Fonck, R.J. Goldston, et al., Appl.Phys.Lett.,**42** (1983) 239;
[2]A.N.Romannikov, A.P. Chernobai, Pl.Phys.Reports, **23** (1997) 1038;
[3]S.P. Hirshman, D.J. Sigmar, Nucl. Fusion, **21** (1981) 1079;
[4]Yu.V.Gott, E.I. Yurchenko, Dokl.Akad.Nauk SSSR, **260** (1981) 1352;
[5]I.A.Kovan, A.N.Romannikov, et al, 24th EPS, Berchtesgaden, 1997, V.21A, 409.