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The effect of off-axis pellet injection on plasma rotation

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1 Introduction

We measured the change in poloidal rotation velocity in the RTP-tokamak (Rijnhuizen Tokamak Project, $R_0 = 0.72m, a = 0.164m, I_p < 140kA, B_T < 2.5T$) caused by the injection of a solid hydrogen pellet by observing the line shift of spectral lines in the vacuum ultraviolet. Depending on the poloidal angle of injection the rotation could be decreased as well as increased. A simple model based on the angular momenta of plasma and pellet could explain the measured changes.

2 Experimental

A 6.650 m normal incidence vacuumspectrometer and a 1 m high resolution Czerny-Turner spectrometer were used to record the changes in poloidal and toroidal rotation after the injection of a pellet. We monitored the change in poloidal rotation by the line shift of the C IV resonance lines at 155 nm. These ions are concentrated around 120 mm from the centre of the plasma. The effect on toroidal rotation was deduced from C III lines at 465 nm, slightly further out.

Pellets were not only injected in the meridional plane, but also off-axis under different angles. The setup at Rijnhuizen allowed only the injection of pellets in and below this plane, as pellet injection was usually considered to have a symmetric effect with respect to this plane. However, pellets are injected with a speed of up to 1.2 $km\,s^{-1}$ while the poloidal rotation is on the order of a few $km\,s^{-1}$. Therefor the relative speed between pellet and plasma is very different depending upon the sign of the injection angle.

To allow a comparison between these two situations a series of experiments was performed, where during one half of the discharges the plasma current as well as the magnetic field B_T were reversed. As a consequence both the poloidal and toroidal rotation were reversed. In series of similar, ohmically heated discharges ($I_p = 80kA, B_T = 2.14T, n_e = 8.8 \times 10^{19} m^{-3}$) a pellet ($5 \times 10^{19}$ atoms) was injected with a speed of 1.015 $km\,s^{-1}$, at an angle α, ranging from 0 to 8^o. It turned out that the change in rotation due to pellet

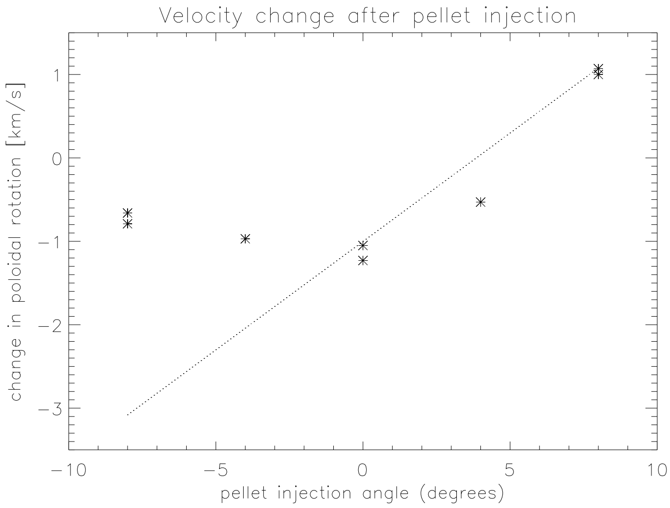

Figure 1: The effect on poloidal rotation due to pellet injection. The $*$ indicate measured values (error $\pm 0.15\ km\, s^{-1}$); the dotted line a very simple first order calculation.

injection depended very much on the injection angle and was not at all symmetric with respect to injection to the meridional plane (see Fig. 1).

3 A simple model for the angular momentum change

As a first approach we considered the plasma as a rigid rotator and assumed that a constant fraction of the pellet was ablated. Assuming a triangular density distribution we can calculate an effective radius of the plasma, b_{plasma}, and hence the angular momentum of the plasma before pellet injection. The angular momentum of the pellet with respect to the plasma is the product of velocity, effective mass - the fraction of the pellet which is ablated - and impact parameter, b_{pellet}. If we take the final angular momentum as the sum of the plasma angular momentum before injection of the pellet and the angular momentum of the pellet we can very simply calculate the change in poloidal rotation and hence the line shift of the C IV lines studied. From this model follows the following formula for the poloidal velocity change :

$$\Delta_v = \frac{v_{pellet} \times \frac{b_{pellet}}{b_{plasma}} - v_{pol}}{(1 + \frac{m_{plasma}}{m_{pellet}})} \tag{1}$$

The resulting calculated velocity change is given by the dotted line in Fig. 1.

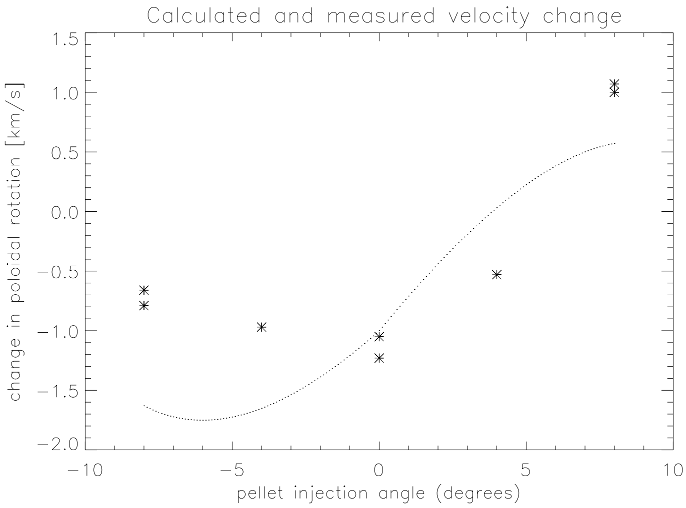

Figure 2: The calculated rotation change, including the effect of a lower fuelling efficiency near the edge. The $*$ indicate measured values, (error $\pm 0.15\ km\, s^{-1}$).

4 Pellet ablation and the impact parameter

Although the simple model of section 3 predicts the order of magnitude of the poloidal velocity change quite well, it is clear from Fig. 1 that this change is a more complicated function of the pellet impact parameter. We introduce now a fuelling efficiency, i.e. the fraction of the pellet which is absorbed into the plasma by ablation, assuming that the remainder will pass through. This fuelling efficiency, f_{eff}, is a decreasing function of the impact parameter :

$$f_{eff} = 0.2 + 0.8 \times (1 - 7.14 \times abs(b_{pellet})) \qquad (2)$$

The numerical factors are chosen to obtain a best fit.

Although the introduction of a fuelling efficiency dependant on the impact parameter clearly improves the fit, as can be seen from Fig. 2, the result is still not satisfying. Another improvement is to assume that the fuelling efficiency is also asymmetric with respect to the rotation. This is a reasonable assumption because the relative velocity of the pellet with respect to the plasma is different for injection against and with the poloidal rotation. We take this into account by multiplying the fuelling efficiency by

$$(1 + k \times b_{pellet}) \qquad (3)$$

where k is of the order of 10.

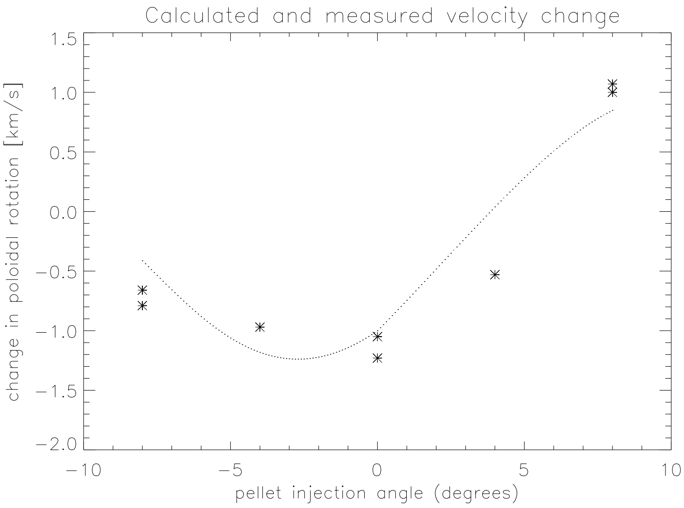

Figure 3: The calculated rotation change, including the effect of a lower fuelling efficiency near the edge. The $*$ indicate measured values (error ± 0.15 $km\, s^{-1}$).

As shown in Fig. 3 this provides a better fit to the measured data. Thus far we have neglected the fact that we do not measure the poloidal rotation at b_{plasma}, $0.027m$, but at the radius where C IV is concentrated, $0.120m$. We should therefor increase the calculated poloidal rotation by a factor of $0.120/0.027 \approx 4$. On the other hand the plasma is not a perfect rigid rotator and the carbon ions follow the field lines, this means that we have to correct for the q-factor ratio between these radii, $0.027m$ resp. $0.120m$. This correction factor is $0.7/2.8 \approx 0.25$. These two factors cancel each other.

The fit we obtained from introducing formulae 2 and 3 is much better than that from our first simple model. We might conclude that ablation indeed is a function of the impact parameter and behaves asymmetric as well.

5 Concluding remarks

The injection of a pellet of solid hydrogen into a tokamak plasma changes the poloidal rotation velocity. The magnitude of this effect depends both directly on the impact parameter, due to the angular momentum involved, and also indirectly, because the ablation efficiency is a function of this parameter. The effect is different for injection against and with the rotation. A simple model can explain these changes both qualitatively and quantitatively.

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