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Ion and mode rotation in the EXTRAP T2R device during discharges with and without the application of feedback control

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Introduction

The application of active feedback control to a reversed field pinch (RFP) plasma provides the opportunity to stabilise resistive wall modes whilst simultaneously affecting internally resonant tearing modes and prolonging the discharge duration [1]. Impurity ion rotation measurements in RFP devices can lead to a greater understanding of plasma flow and transport and through the study of velocity time evolution correlations to changes in radial profiles, global plasma parameters and resonant tearing modes can be drawn [2-3].

A series of experiments have been carried out at the EXTRAP T2R [4] RFP in order to study the relationship between the impurity ion and tearing mode rotations and in particular the effect of the application of active feedback control.

Experimental details and analysis

EXTRAP T2R [4] is a medium sized RFP device with an all metal first wall and with major and minor radius of 1.24m and 0.183m respectively. Two series of 85kA discharges were taken, one in which active feedback control was applied.

Ion rotation velocity measurements were made with a 1m spectrometer of Czerny-Turner design (2400 grooves/mm grating, 0.3µm slit) operated in 2nd order with an optical multi-channel analyser detector. For toroidal velocity measurements, the fibre to the spectrometer was placed in a horizontal toroidal port in the vessel mid-plane with a line-of-sight counter to the plasma current direction. The reference zero velocity position of the line was obtained by periodically shifting the fibre to a poloidal port looking through the plasma centre. The two lines-of-sight used in these measurements are shown in figure 1. Data recording was limited to a single line enabling measurements to be repeated every 2ms.

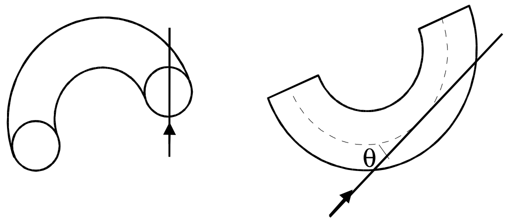


Figure 1: Lines-of-sight for zero velocity and toroidal velocity measurements respectively.

In EXTRAP T2R oxygen is the main intrinsic impurity. The lines in this study were OII at 4414.9Å, OIII at 3759.9Å, OIV at 3385.5Å, OV at 2781.0Å and OVI at 3433.7Å [5].

The toroidal rotation causes the line, as viewed through the toroidal line-of-sight, to be Doppler shifted such that $v_{actual} = c\ (\lambda_{tor} - \lambda_{v=0})/(2\ \lambda_{v=0} \cos\theta)$ where λ_{tor} and $\lambda_{v=0}$ are the wavelengths of the line peak as observed on the toroidal and central poloidal lines-of-sight respectively, c is the speed of light and θ is the angle between the line-of-sight and the direction of rotation. The wavelength position of an observed spectral line was calculated by fitting a Gaussian curve to the line. The zero velocity position $\lambda_{v=0}$ was taken to be the average position in the scans with the line-of-sight on the central poloidal port.

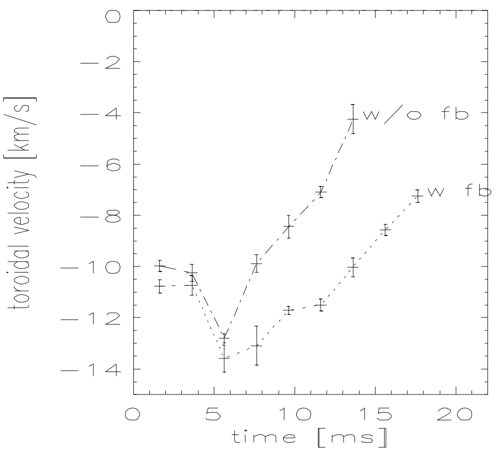
The toroidal rotation velocity was calculated for each scan interval during the discharge. The $\cos\theta$ factor for each ionisation stage was the average $\cos\theta$ along the line-of-sight weighted by the line-of-sight emission profile of that ion [6]. Results from several discharges were averaged to give the overall ion toroidal rotation results shown in the figures.

The helical angular phase velocity of the internally tearing modes m = 1, n = -12 to n = -31 was obtained using a 2 x 64 array of m = 1 connected sensors measuring the toroidal magnetic field component. Projection of the helical angular phase velocity along the toroidal direction provided the mode toroidal velocity [7].

Results

OVI was the most centrally peaked (around r/a = 0.2) of those measured, with a broad profile. Figure 2 shows the evolution of the toroidal rotation velocity of the OVI ion, the error bars are calculated from the averaging over several discharges. Figure 3 shows the evolution of the toroidal rotation velocity of the most centrally resonant tearing mode n = -12, located around r/a = 0.27. In both figures the dotted and dot-dashed curves correspond to active feedback and non-feedback operation respectively. Negative velocities correspond to rotation in the same direction as the plasma current.

Good agreement can be seen between the toroidal rotation velocities of the OVI ion and the n = -12 mode. Both ion and mode have a toroidal velocity of similar magnitude that initially increases to around 6ms and then decreases until the end of the discharge. Use of active feedback control slows down the second phase decrease in both cases. The good agreement indicates that the central mode is co-rotating with the plasma flow.



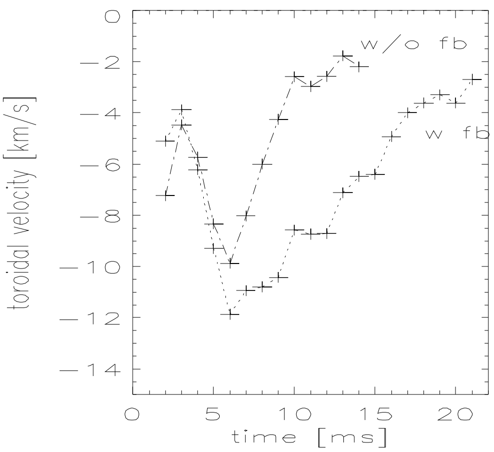


Figure 2: OVI toroidal velocities

Figure 3: Toroidal velocity of n = -12 mode

The toroidal velocities of OII to OV are shown in figure 4. An initial increase followed by a more gradual decrease in velocity is demonstrated for all the ions with the application of active feedback control causing a slowing down of the second phase decrease. The toroidal velocity is less for the more edge peaked lower ionisation stages. The vertical shift in velocity between cases with and without active feedback may in part be accounted for by uncertainty in the zero velocity position due to the reduced intensity of the spectral line observed on the shorter poloidal line-of-sight.

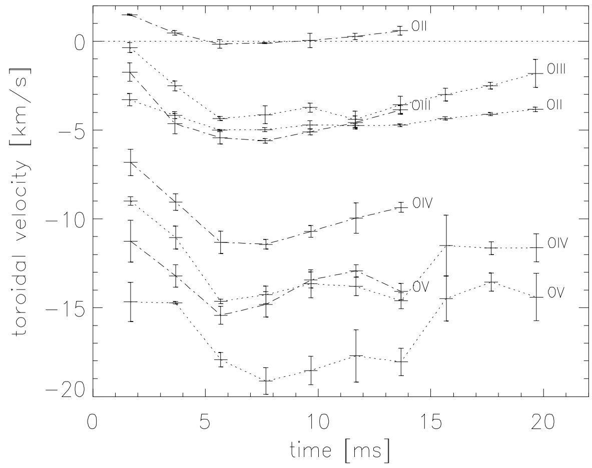


Figure 4: OII to OV toroidal velocities with (dotted) and without (dot-dashed) active feedback

The time evolution of the toroidal velocity of the tearing modes n = -31, -25, -20, -15 and -12 is shown in figure 5. It is evident that n = -31, which is closest to the reversal surface (r/a = 0.7), is rotating in the opposite direction to the most central, n = -12, and that the velocity time evolution is also different. Without feedback the velocity increase begins to level off towards the end of the discharge, with feedback the increase is more gradual.

The most outer mode n = -31 is resonant around r/a = 0.71 close to the peak location of OII and OIII. In contrast to the similarities seen between the most central ion and mode, the time evolution of the edge resonant modes in figure 5 is very different from that of the lower oxygen ionisation stages in figure 4. Close examination of figure 5, however, suggests a possible explanation as the pattern of the mode velocity time evolution is seen to be approximately the same for all modes (including those not shown) with just a magnitude shift. It is suggested that the more edge located modes were phase-locked to the central modes. The n = -12 mode was, as seen in figures 2 and 3, rotating with the ions and the mode phase-locking [7] causes the velocity of the other modes to be locked to the central mode velocity variations. A possible explanation for the observed deviation of the tearing mode toroidal velocities at the edge from that of the ion velocities is the fact that magnetic measurements cannot provide information on parallel velocity, i.e. the velocity of the tearing modes along the helical magnetic field lines.

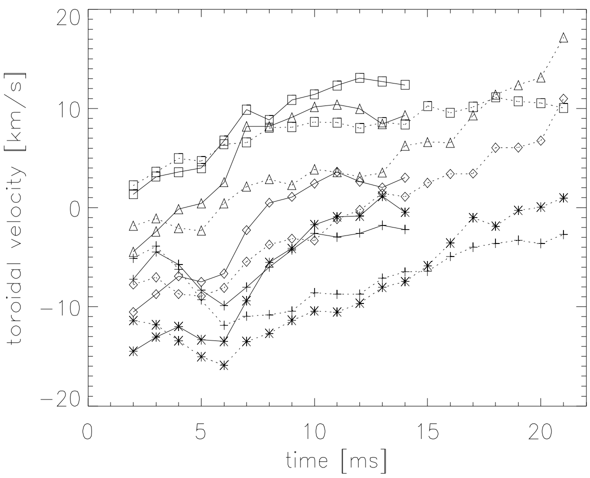


Figure 5: Rotation velocities of the n = -31(□), -25(Δ), -20(◊), -15(*) and -12(+) tearing modes with (dotted) and without (solid) active feedback

Conclusions

Measurements of the toroidal rotation velocities of impurity ions and of internally resonant tearing modes indicate that the most central ion OVI and mode n = -12 rotate together. Toroidal velocity initially increases and then, more slowly, decreases. Active feedback control prolongs the discharge and causes a reduction in the rate of the second phase decrease. A similar behaviour is observed for all the ions with a lower toroidal velocity for the more edge peaked lower ionisation stages. The modes demonstrate a phase-locking behaviour to the most central n = -12 which causes differences in the apparent velocity time evolutions of the edge located modes and ions. The velocity component parallel to the field lines is not included by the mode calculations and it is suggested that this plays a significant role towards the edge of the plasma and can at least partly account for the observed differences.

[1] P. R. Brunsell, et al., Phys. Rev. Lett. **93** (2004) 225001
[2] J.-A. Malmberg, et al., Phys. Plasmas **11** (2004) 647
[3] L. Carraro, et al., Plasma Phys. Control. Fusion **40** (1998) 1021
[4] P. R. Brunsell, et al., Plasma Phys Control. Fusion **43** (2001) 1457
[5] http://physics.nist.gov/PhysRefData/ASD/
[6] M. Kuldkepp, et al., contribution this conference
[7] M. Cecconello, et al., contribution this conference