Braking of Plasma Rotation by Non-axisymmetric Magnetic Fields in EXTRAP T2R

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Introduction

External magnetic perturbations exist in fusion confinement devices. These perturbations can be unavoidable field errors or controlled active perturbations produced by external coil systems. Externally induced magnetic perturbations are routinely used for suppression of a broad range of unstable resistive wall modes [1], for the suppression of edge localized modes [2] and for the rotation of neoclassical tearing mode islands to positions, where the ECCD stabilization is optimal [3]. These magnetic perturbations can interact with rotating tearing modes and may cause reduction in tearing modes rotation and hence can cause braking in plasma rotation. Plasma rotation braking induced by externally applied non-axisymmetric magnetic fields has been experimentally observed in the EXTRAP T2R reversed field pinch [4] and may be related to neoclassical toroidal viscosity braking [5]. Following work is carried out in order to do systematic and empirical study of plasma rotation braking in the presence of applied external non resonant magnetic perturbations (NRMP) in EXTRAP T2R.

Experimental Setup

EXTRAP T2R is a RFP machine with major radius $R = 1.24\ m$ and minor radius $a = 0.183\ m$. The typical plasmas are characterized by $I_p \sim 100kA$, $T_e = 300\text{-}400eV$ and $N_e \sim 10^{19}\ m^{-3}$. The vacuum vessel is located at $0.192m$ and has a time constant $\tau_V \approx 0.28ms$. The shell is located outside the vacuum vessel at $0.198m$ and has a nominal long shell time constant $\tau_W \approx 13.8\ ms$. The typical discharge duration is between 70 and 90 ms. The device uses an all metal first wall consisting of a stainless steel vacuum vessel and a distributed array of molybdenum limiters [6]. It is equipped with a feedback system that includes power amplifiers, active coils, sensor coils, and the digital controller. The active saddle coils (4 x 32) are placed outside the shell while the sensor coils (4 x 32) are located inside the shell. At each toroidal position, active coils and sensor coils are $m = 1$ pair-connected.

Data Analysis Method

The mode phase velocities are obtained by analysis of magnetic data from an array of B-pol magnetic pick up coils (4 x 64). For data analysis of velocity braking, two time intervals are chosen. First interval is before the application of NRMP while second interval is after the application of NRMP. In both of these intervals, velocity is constant on slow time scale (around *0.1 ms)*. q-profile is computed from α-θ_0 model corresponding to experimental values of equilibrium parameters ($\mathcal{F}$ and Θ). Plasma velocity profile is estimated by assuming that tearing modes co-rotate with local plasma and vice versa. Error bars shown in quantities like change in velocity and change in radiation intensity indicate the variation of velocity and radiation in time. The error bar shown for radial positions are calculated from the fluctuations in equilibrium parameters in time during the discharge.

Results and Discussion

In figure 1, the effect of NRMP on the tearing mode velocity and plasma flow is shown for shot 21967. The active coils and the feedback system of EXTRAP T2R are used to apply an external non-resonant magnetic perturbation with harmonic (*1,-10*) between *20 ms* and *60 ms*. All other m=1 harmonics in the range (-15, 16) (error fields and resistive wall modes) are suppressed by the feedback system. In figure 1(a) the time evolution of plasma discharge current is shown. Figure 1 (b) shows the temporal behaviour of applied NRMP with a reference amplitude *0.3 mT*, Figure 1(c) shows that NRMP with relatively low amplitude produces a clear reduction in the velocity of a core resonant tearing mode (*1,-12*). In the same frame, it can be seen that the plasma fluid rotation is also reduced. The fluid rotation during the braking experiments is estimated from ion Doppler spectroscopy using the oxygen impurity ion OV line at 2781A. The lower reduction compared to the mode velocity is possibly due to the fact that the fluid rotation is a line integrated measurement.

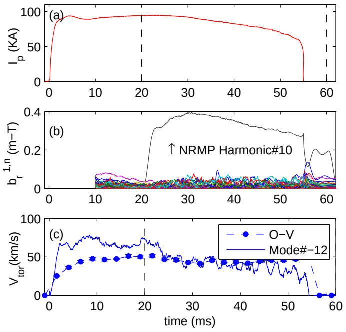

Figure 1: *NRMP effect on TM velocity and plasma flow. Time evolution of (a) plasma current (b) amplitude of external harmonics (c) toroidal velocity.*

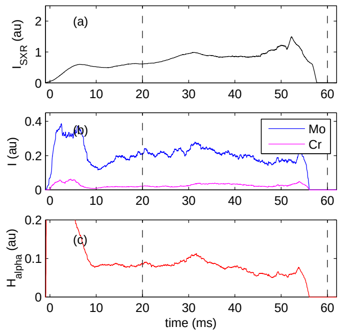

Figure 2: Radiation versus time. Time evolution of intensity of (a) soft X-Rays, (b) impurities, (c) hydrogen alpha line.

The non-axisymmetric magnetic field perturbation affects the plasma boundary, and may lead to enhanced localized plasma wall interaction. In figure 2, effect of applied NRMP on time evolution of radiation from different impurities and hydrogen are shown for shot 21967. Figure 2(a) shows the time evolution of the soft X-ray emission, which is measured by using a surface barrier detector. This measurement is an indicator of the variation of the overall impurity content in the plasma in time. Figure 2(b) shows the time evolution of line emission from metal impurity atoms Mo and Cr, which indicate the level of impurity influxes from the limiters and the vacuum vessel materials, respectively. Figure 2(c) shows the time evolution of line radiation from hydrogen atoms from spectroscopic measurements, which indicates the level of fuel gas recycling at the wall. In all these three frames, although there is a rise in intensity of radiation due to localized plasma wall interaction yet the rise is not very significant.

In figure 3, the effect of applied NRMP on different radiation intensities is shown for various amplitude of applied NRMP. All three frames show a similar trend that indicates a qualitative rise in the soft X-ray radiation, the impurity line radiation and the hydrogen line radiation levels respectively with the increase in amplitude of applied NRMP. It is obvious that at low helical field amplitudes the rotation braking takes place without significant rise in all the mentioned radiation levels but on the other hand, if the applied helical field amplitude is increased above a critical value, all the mentioned radiation levels are indeed increased significantly, indicating enhanced plasma wall interaction.

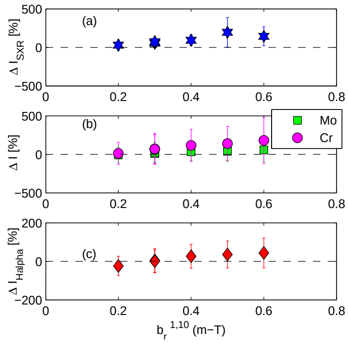

Figure 3: *Effect of NRMP on radiation intensity. Change in intensity of (a) soft X-Rays, (b) impurities, (c) hydrogen alpha line.*

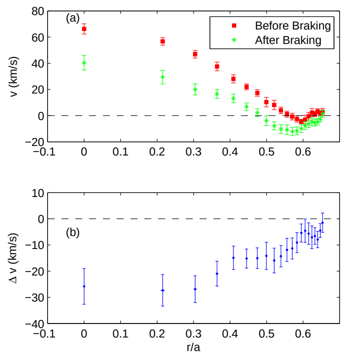

Figure 4: *Plasma flow radial profile (a) velocity before and after braking, (b) change in velocity.*

Figure 4 shows the effect of applied NRMP on radial profiles for shot 21967, for which low NRMP amplitude ≈ *0.3 mT* leads to braking without any significant effect on radiations. The resonances are calculated using the α-θ_0 model for the RFP equilibrium. The velocity and the change in velocity of each mode are then plotted at its corresponding resonant radius. These estimations have been done from the measurements of resonant tearing mode phase velocities. In figure 4(a), the velocity profiles before and after braking are shown. It can be seen that NRMP produces a reduction of the velocity and this effect is prevailing in the entire core region. This suggests that the NRMP produces a non-local effect. In figure 4(b), the profile for change in plasma rotation is obtained from the difference in velocities after and before braking. At inner most core region, the velocity reduction is approximately 25km/s, but closer to edge, the velocity reduction is smaller and almost negligible at r/a≈0.6. So braking is most dominant at inner core region. In figure 5, the effect of the amplitude of the external NRMP in the braking mechanism is shown. An NRMP with harmonic (*1,10*) but with amplitude from 0.1 to 0.6mT, is applied. In figure 5(a), the velocity variation for several tearing modes (m=1, n from -16 to -12) is plotted. Each colour refers to a different shot (i.e. different NRMP amplitude).

It is clear that, for the same tearing mode, the velocity depends on the perturbation amplitude. Moreover, with the same amplitude perturbation, the velocity reduction is lower for tearing modes resonant far from the axis.

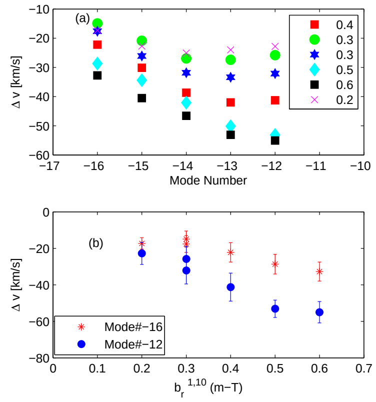

Figure 5: *Effect of NRMP on TM velocity. Change in TM velocity versus (a) mode number (b) amplitude*

In figure 5(b), two tearing modes (1,-12) and (1,-16) are plotted versus the amplitude of the perturbation. At 0.6mT the absolute difference is maximum and is approximately 25km/s. It is obvious that braking effect in terms of the observed decrease of the plasma velocity clearly increases generally with the amplitude of the non-resonant helical field.

Conclusions

The NRMP produces the braking of the entire velocity profile and braking effect clearly increases with increase in NRMP amplitude. The radial profile of the velocity braking is indicating a non-local effect. If the NRMP amplitude is increased too high, radiation is increased, indicating enhanced plasma wall interaction, which may cause velocity braking due to charge-exchange collisions. At low NRMP amplitude, the braking takes place without significant effect on radiations. It points to another effect causing the braking that may be the enhanced neoclassical toroidal viscosity due to the applied non-axisymmetric field. However, quantitative comparison of the results is needed to be made with the theoretical expectation before making a more conclusive statement.

Refrences

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