Experimental observation of non-resonant toroidal rotation braking with a magnetic perturbation field on JET

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Abstract

The paper presents an analysis of toroidal rotation profiles under the influence of a non-axisymmetric magnetic perturbation in JET plasmas with n=1 or n=2 mode numbers of the perturbing fields. A scaling of the torque with $(\delta B/B)^{\alpha}$ is derived from the experimental data and torque profiles are compared to predictions from neoclassical toroidal viscosity (NTV) theory.

Introduction

Magnetic perturbation fields in tokamaks can brake plasma rotation and affect the global performance through the creation of MHD instabilities. On JET magnetic perturbation has been applied for ELM control purposes. NTV exerts a torque on the plasma and modifies the toroidal rotation velocity (v_ϕ) profile. In general, the NTV torque can be categorized in a resonant and a non-resonant class. Most JET plasmas have transport fluxes in the $1/\nu$ and ν regimes and fall in the non-resonant category (ν is the collision frequency), although also the superbanana regime can be important for low ExB drift speeds. When a collisional boundary layer is introduced (between trapped and un-trapped particles) the NTV contribution in the ν regime is enhanced and scales as $\sqrt{\nu}$ [1, 2]. General parameters of a typical discharge in which error field correction coils (EFCC) have been used, are shown in figure 1 (B_t/I_p = 1.7T/1.7MA). 12 MW of NBI heating power was applied (fig. 1a). The current in the EFCC (I_{efcc}) was ramped up from 0 to 2.5 kA in the time interval t = [6.0 s – 6.5 s] and stays at that level until t = 8.0 s (fig. 1b). In [3] measurements of rotation braking have been compared to calculations of the NTV torque for one discharge with n=1 toroidal mode number of the perturbation field, the torque profiles were taken during the stationary phase of the perturbation, i.e. at the end of the I_{efcc} ramp. This paper complements the previous study by considering both discharges with n=1 and n=2 perturbation fields, and by looking at the early perturbation phase, i.e. when the influence on the rotation velocity is mainly due to the NTV torque and momentum transport can be neglected. In addition, during the first few 100

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ms of the I_{efcc} ramp, the density remains constant and therefore the braking of the toroidal rotation velocity is directly related to the time evolution of the toroidal momentum.

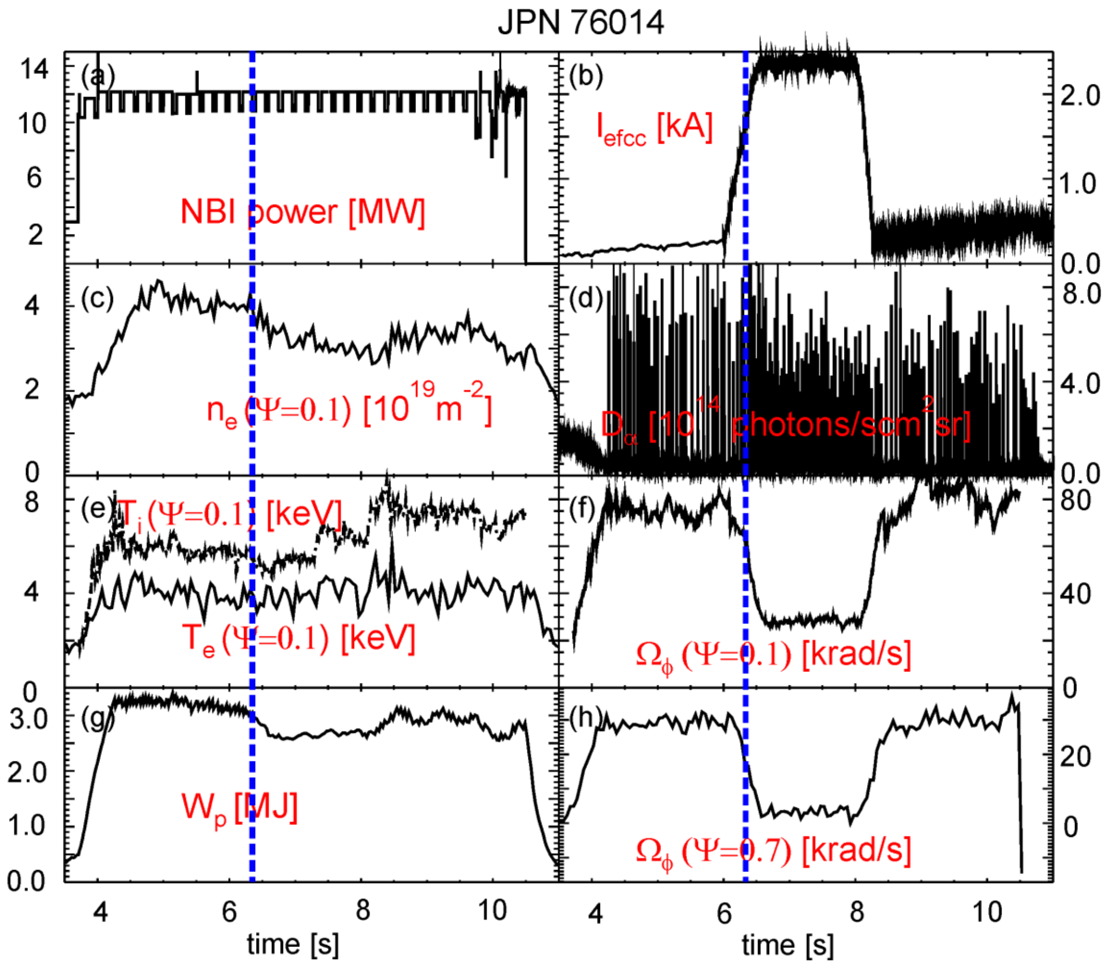

Figure 1. General parameters of JPN 76014 as a function of time ; (a) the NBI heating power, (b) current in two sets of error field correction coils, (c) central and edge electron density, (d) D-α signal in the outer divertor, (e) central electron and ion temperature, (f) central angular momentum, (g) diamagnetic energy and (h) edge angular momentum. The vertical line is the time at which torque profiles have been calculated (t=6.3s).

Qualitative comparison of toroidal momentum evolution and magnetic perturbation

A scaling of the torque with perturbation amplitude, $(\delta B/B)^\alpha$, is derived from the experimental data and compared to predictions of NTV by Shaing [1, 2]. According to [1] the total momentum evolution $d(NMv_\phi)/dt \sim n^2 (\delta B/B)^\alpha (1/\nu_{ii})$ for $\nu_{ii}/\varepsilon > |q\omega_{ExB}|$, where N is the plasma density, M is the mass, ν_{ii} is the ion-ion collision frequency, ε is the inverse aspect ratio, *q* is the safety factor and ω_{ExB} is the poloidal $E_r x B_\phi$ drift frequency. In figure 2 (a) a number for α is determined from the experimental data; dv_ϕ/dt is plotted as a function of the I_{efcc} and α is derived from a least square fit in the initial phase of the braking (low I_{efcc}) in order to ensure a plasma with nearly constant density (N and M do not change in time). In this discharge α is found to be around 1.6 – 1.7 for the three different radial locations. In figure 2 (b) a complete radial rotation profile was considered and α is found to be in the region 1.5 – 2 everywhere, close to the theoretical predictions [1]. For JPN 76014 the mode number of the perturbation was n = 1 and for JPN 75794 the phasing of the current in different sets of coils was changed to obtain an n = 2 perturbation mode. In both cases values for α are similar, suggesting that the n^2 scaling of [1] is indeed valid.

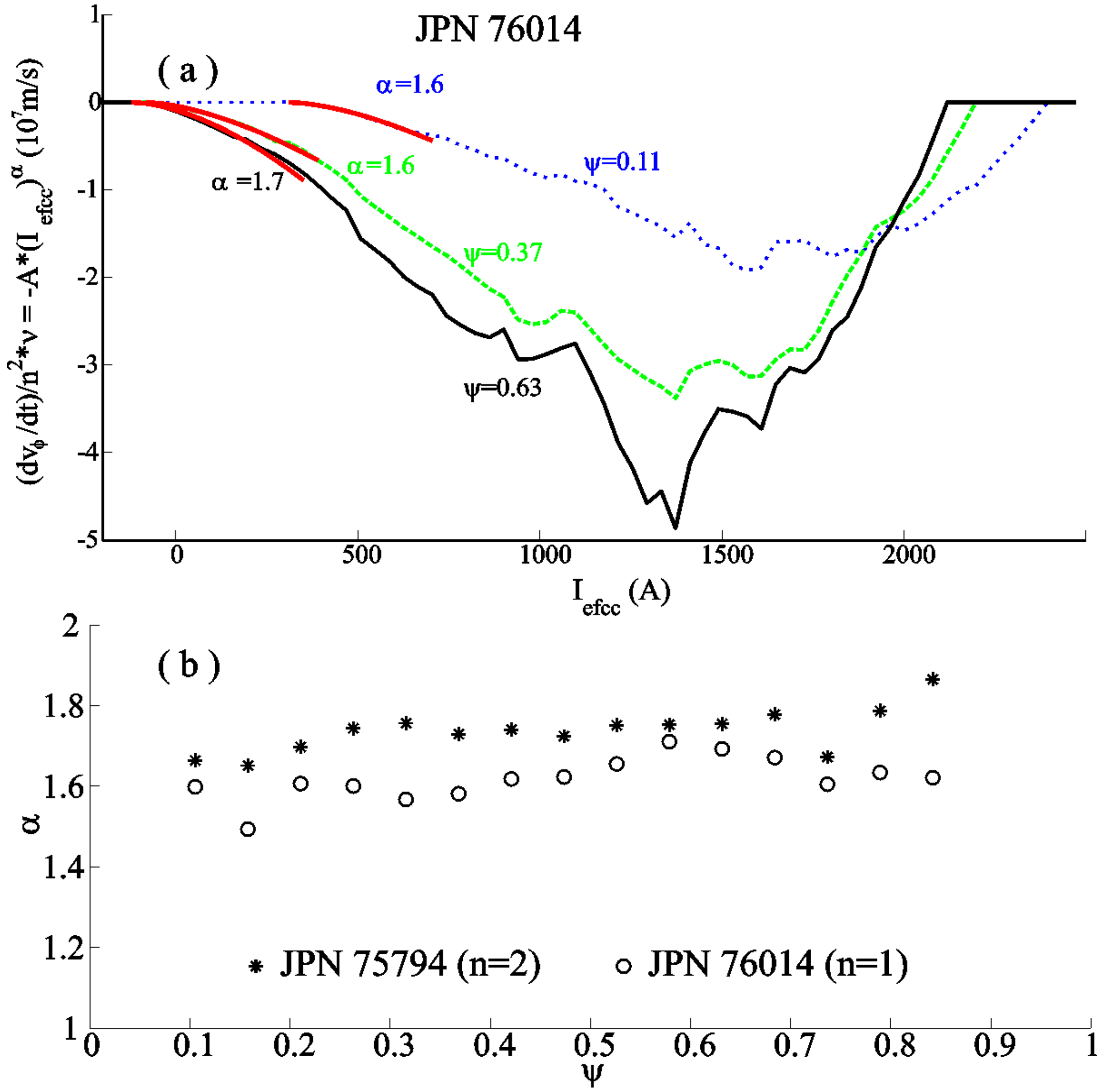

Figure 2. (a) Determination of the scaling of the torque with perturbation amplitude (α) for three different radial locations for JPN 76014, (b) radial variation of α for discharges with different mode number of the magnetic perturbation : n=1 for JPN 75794, n=2 for JPN 76014.

Experimental and theoretical NTV torque profiles

Experimental torque profiles (integrated over a flux surface, following the method in [4]) have been compared to theoretical predictions from NTV theory as explained in [1 – 4], for different collisionality regimes. Momentum transport has been neglected in the analysis; the profiles are taken less than 500 ms after the onset of the perturbation field, which is shorter than the typical momentum confinement time. Results have been plotted in figure 3. It can be seen that the experimental results are a factor 2 – 4 lower than the predicted NTV torque in the 1/ν regime and two orders of magnitude larger than the torque in the √ν regime. The ν regime has an even lower torque than √ν and is not plotted here [3]. The reason for the remaining discrepancy is unclear at present, but could be due to additional torque contributions, such as fast ion losses [5], NBI momentum input, electromagnetic forces on rotating magnetic islands (resistive MHD modes), fluid viscous forces between adjacent flux surfaces, etc. Also the collisionality, ion pressure and rotation frequency are parameters that enter the equations for the theoretical force calculations and have a limited accuracy of typical 10%. In addition, only the vacuum perturbation field has been used in the calculations, the screening effect of the plasma was not considered. Overall it can be seen that for JET the torque profile is broad, leading to a strong braking of the full rotation profile, which is different from the observations on NSTX, where the NTV torque profile is peaked around mid-radius for the applied n=3 field configuration [4].

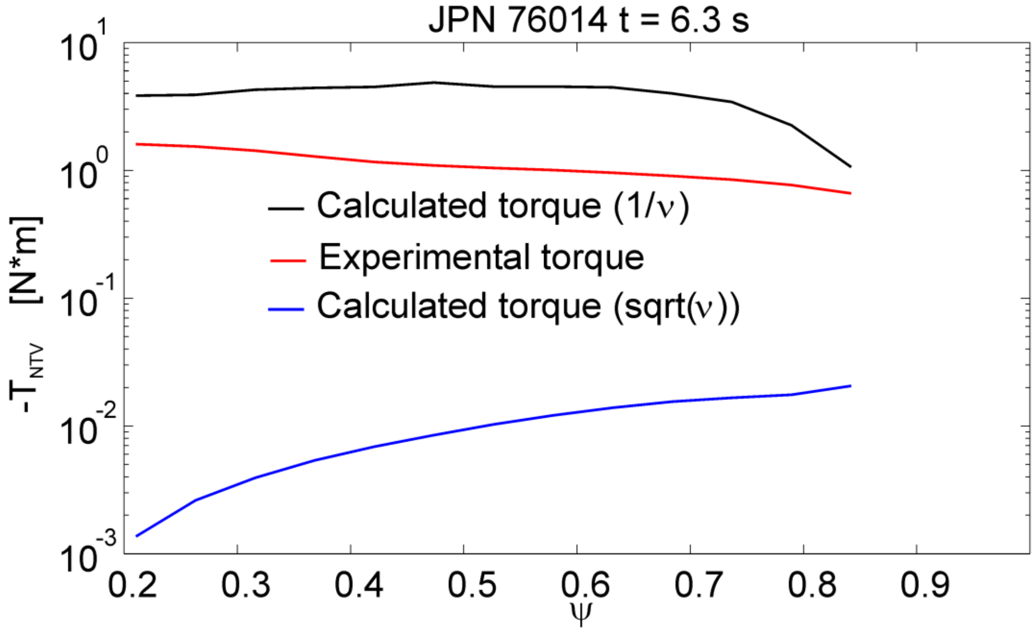

Figure 3. Experimental torque profile and theoretical predictions from NTV in the $1/\nu$ and the $\sqrt{\nu}$ regime.

Conclusions

For JET plasmas with magnetic perturbation a qualitative agreement has been found between the braking of the plasma rotation and the predictions from neoclassical toroidal viscosity for low perturbation amplitude. Quantitatively a moderate discrepancy exists between experimental and theoretical torque profiles, possibly due to other sources of torque that are present or the plasma response to the perturbing field.

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