Neoclassical toroidal viscous torque due to 3D magnetic perturbations in EU-DEMO

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A number of phenomena lead to non-axisymmetric (3D) magnetic perturbations in tokamak plasmas. Natural causes within the plasma include magnetohydrodynamic (MHD) modes such as a saturated helical core. Artificial perturbations are either unintentional in the case of ripple and error fields, or intentional for the mitigation and suppression of edge-localized modes. Resonant magnetic perturbations (RMPs) are aligned with the magnetic field line pitch at rational flux surfaces and may introduce local shielding currents, island chains and field line stochastization. Besides the resonant components of a perturbation, its non-resonant part induces distortions in the nested flux surface geometry. One important concequence of non-resonant 3D perturbations is neoclassical toroidal viscous (NTV) torque [1]. Significant toroidal rotation breaking by such a torque is expected to be detrimental to plasma stability and confinement.

This work is part of an ongoing effort to quantify 3D effects in the design of the EU-DEMO tokamak and how they affect aspects of physics and technology. Here we consider the error-field correction coils (EFC, fig. 1). The purpose of such coils is to reduce the resonant component of perturbations with toroidal harmonic $n = 1$. Depending on the exact setup, this can have side-effects of increasing other harmonics in the perturbation spectrum as well as the non-resonant part of the 3D perturbation. At the moment, three design options are considered for EFCs: (1) coils near the vacuum vessel wall, (2) coils at the inner boundary of the toroidal field coils, and (3) coils at their outer boundary (Fig. 1). Here we consider variant (2). The goal here is to quantify NTV torque from the induced perturbation field and to assess whether it introduces significant rotation braking compared to torque from anomalous transport.

The perturbed magnetic field including the linear MHD plasma reponse was computed via the code MARS-F. Subsequent toroidal torque calculations were performed with the quasilin-

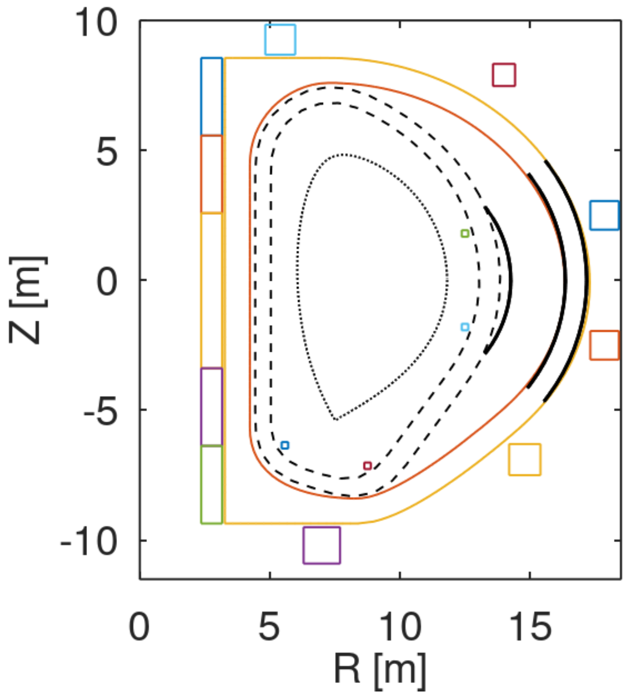

Figure 1: The coils system as planned for DEMO. The black solid curves are the three possible locations for the field correction coils (1) near the vacuum vessel wall (2) inside the toroidal field coils and (3) outside of the toroidal field coils. The dotted black line is the last closed flux surface, shown for reference.

ear kinetic NTV models in the code MARS-Q and NEO-2 [4, 5]. Both codes are able to treat the resonant plateau regime by drift-orbit resonances that is important for ion NTV torque. This is important, as semi-analytical models that include only the superbanana plateau regime have been shown to underestimate ion NTV torque at reactor conditions. Higher collisionality regimes realized usually for electrons are expected to be treated more accurately by the integro-differential collision operator in NEO-2 than the Krook operator in MARS-Q. Here we show preliminary results from NEO-2 using the magnetic perturbation field spectrum in Hamada coordinates from the fluid variant of MARS-F. Plasma parameters and toroidal rotation profiles are set to typical values for DEMO scenarios. Results are shown for a perturbation field produced by 100 kA-turns in the EFCs phased for toroidal $n = 1$. The resulting non-resonant perturbation of the magnetic field modulus B in the bulk plasma is of the order $\varepsilon_B = 10^{-3}$ relative to the axisymmetric field B_0 as shown in fig. 2. In the quasilinear transport regimes realized here, the NTV torque scales with ε_B^2. In fig. 3 the slowing down rate of the toroidal torque is shown. It has been calculated according to Eq. (34) of [4]. Also shown is the slowing down rate calculated from a global argument (following Eq. (33) of the same reference) and the value at which NTV and toroidal torque from anomalous transport would have approximately the same strength, as-

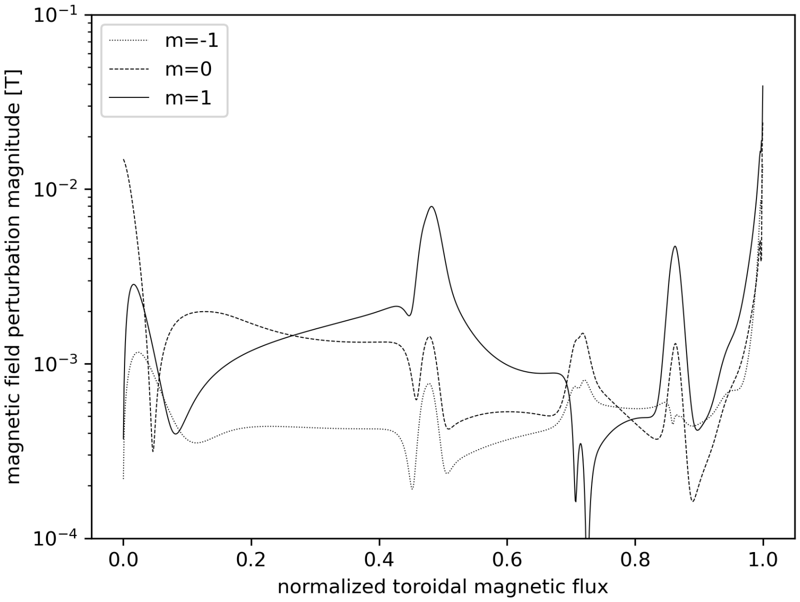

Figure 2: Spectrum of magnetic perturbation harmonics B_{mn} for $n = 1$ in Hamada coordinates computed by MARS-F.

suming $1m^2/s$ for the anomalous radial diffusion coefficient. It can be seen that over most of the radial coordinate NTV is stronger. NTV is thus expected to play a significant part in the slowing down of the plasma, and should not be neglected. For the same parameters the calculated torque density is shown in fig. 4. From these first results we conclude that the NTV torque from the error field correction coils planned in DEMO is significant compared to anomalous transport timescales at their maximum current. Further investigations are required to determine the exact impact in typical scenarios and possible implications on design and placement of these coils.

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References

[1] K.C. Shaing, Phys. Rev. Letters **87**, 245003 (2001)

[2] C.G. Albert, M.F. Heyn, G. Kapper, *et al*, Phys. Plasmas **23**, 082515 (2016)

[3] C.G. Albert, M.F. Heyn, S.V. Kasilov, *et al*, 44th EPS Conference on Plasma Physics ECA 41F P1.182 (2017)

[4] S.V. Kasilov, W. Kernbichler, A.F. Martitsch, *et al*, Phys. Plasmas **21**, 092506 (2014)

[5] A.F. Martitsch, S.V. Kasilov, W. Kernbichler, *et al*, Plasma Phys. Contr. Fusion **58**, 074007 (2016)

[6] P. Piovesan, V. Igochine, F. Turco, *et al*, Plasma Phys. Contr. Fusion **59**, 014027 (2016)

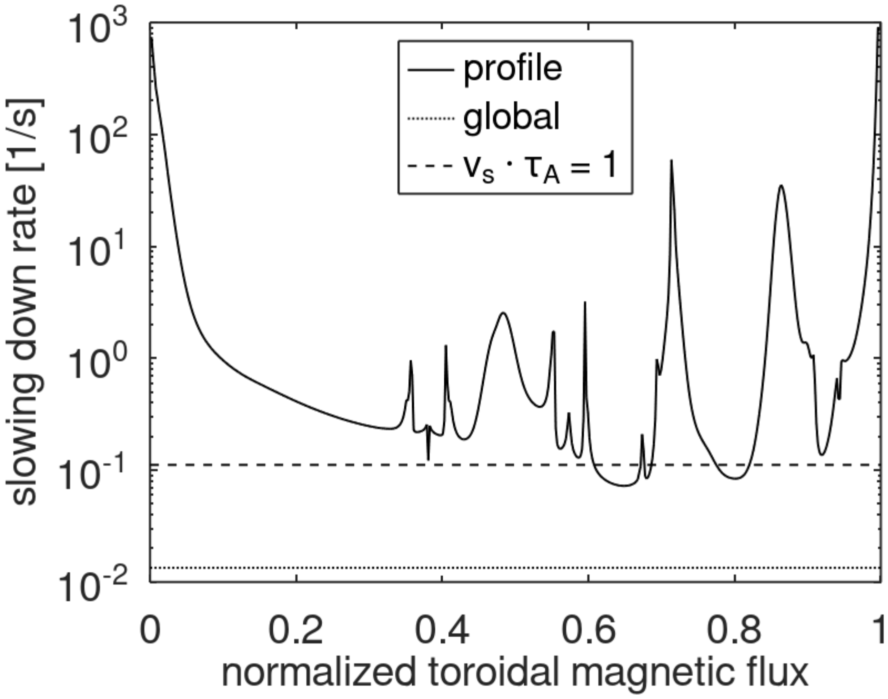

Figure 3: Radial profile of the slowing down rate as a function of toroidal flux. Also indicated are the values from a global calculation, and the value at which the product of slowing down rate (v_s) and anomalous transport time (τ_A) is one.

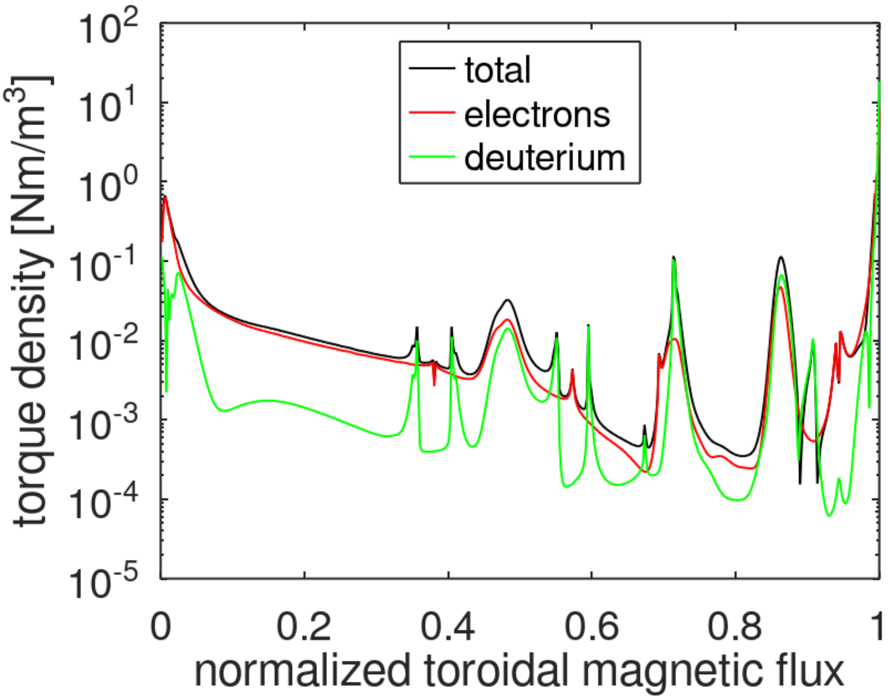

Figure 4: Radial profile of the torque density for electrons (dotted), ions (dashed) and total (solid).