§5. Comparison of 3D Error Field Effects in LHD and Tokamaks

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Error fields can exist in fusion device due to imperfect magnets, and can degrade plasma confinement by generating unexpected activity of magnetic islands. This is well known in both LHD and tokamaks but with different aspects, and thus parametric and theoretical comparisons have been made to better understand error field physics, or in general 3D field physics, in both devices.

The intrinsic error field in LHD was identified by electron gun experiments, and it was shown that the error field can be compensated by RMP coils, with currents -120A/T, in 7-O configuration [1)]. However, this identification and compensation, made in vacuum, are not consistent with recent RMP experiments and their implications [2)]. That is, (1) plasma response was observed very differently in two toroidal (opposite) phases even if RMP currents were same and much higher than 120A/T, (2) magnetic islands are enhanced even if RMP field was opposed to vacuum error field and rather healed when RMP field was aligned with error field.

This inconsistency observed by plasma response compared to vacuum prediction is in fact well-known in tokamaks, since perturbed plasma currents are often more influential over external coil currents [3)]. In LHD plasma experiments, it is found that healing data with different RMP currents indicate that healing boundary can be consistently combined with two parameters, normalized β_T to applied field, $\beta_T/[(\delta B-\delta B_{err})/B]$, and collisionality ν^* [4)]. Here an offset δB_{err} by intrinsic error field is necessary, unless RMP field $\delta B >> \delta B_{err}$. Fig. 1 shows the combined healing data with three different RMP currents, 400A/T, 600A/T, 1440A/T, and with $\delta B_{err}/B=-4.0\times10^{-4}$, where one can see healed and unhealed cases can be well separated.

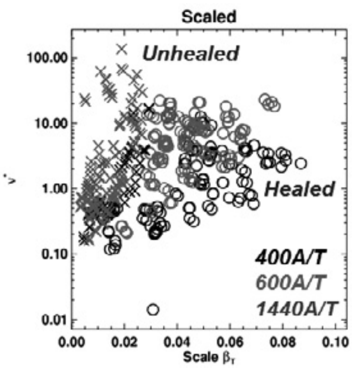

Fig. 1. Combined healed (O) and unhealed (×) data as functions of scaled β_T and collisionality.

The offset amplitude implied by healing data corresponds to -371A/T, which is much higher than and has an opposite direction to vacuum compensation, -120A/T, since it means +371/A/T would be needed for compensation. This is in fact consistent with recent RMP experiments, and indicates it will be necessary to revise error field compensation, in the presence of plasma. A compass scan is well-known for this purpose in tokamaks, but if difficult in LHD, at least a finer scan of RMP currents from -1.0kA/T to 1.0kAt, in 6-O configuration, will be proposed in the next campaign.

The LHD results also imply self-healing threshold can be well represented by two physical parameters, β_T and ν^*. This motivated the investigation of locking error field scaling by physical parameters, Eq (1), rather than engineering parameters, Eq (2), that have been popular in tokamaks.

$$\delta B/B_T \propto \beta^{0.9\pm0.16}\nu^{*0.4\pm0.05}\rho^{*-0.2\pm0.28}, \qquad (1)$$

$$\delta B/B_T \propto n^{1.3\pm0.09}B_T^{-1..7\pm0.12}R^{0.60\pm0.15}, \qquad (2)$$

where ρ^* is the normalized ion sound Larmor radius, n is the density, R is the major radius of the plasma. However, still one can see original scaling in Eq (2) is better with smaller deviations, although engineering parameters such as density is found irrelevant in LHD healing threshold.

The two different representations in scaling between tokamak locking and LHD healing are perhaps manifest by obviously different nature of island dynamics in two cases. That is, tokamak locking is governed by small islands in the presence of substantial inertia whereas LHD healing occurs from large islands without strong rotation. One of outstanding theories for tokamak locking has been recently proposed by R. Fitzpatrick. By taking into account $1/\nu$-regime flow damping and ion polarization effects for small islands, the linear density correlation in tokamak locking threshold has been successfully reproduced [5)]. For LHD, on the other hand, C. Hegna applied the Rutherford equation to describe non-linearly saturated islands, and thereby linear β scaling in LHD healing threshold has also been successfully reproduced [6)]. These two theoretical progresses imply that 3D error field physics can be well explained if appropriate neoclassical flow damping model and island dynamics are applied, and that advanced neoclassical calculations such as FORTEC-3D can be used to improve understanding of error field effects and their predictability.

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4) Narushima, Y. et al.: Nucl. Fusion **48** (2008) 075010
5) Fitzpatrick, R.: Plasma Phys. Contol. Fusion **54** (2012) 094002
6) Hegna, C.: Phys. Plasmas **19** (2012) 056101