ERROR FIELD IDENTIFICATION THROUGH TORQUE BALANCE ON A MAGNETIC ISLAND WITH ROTATING MAGNETIC PERTURBATION

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This study introduces an innovative technique for identifying error field (EF) by analyzing torque balance on a saturated magnetic island. This method facilitates rapid and customized error field identification under various plasma conditions. Time-resolved EF measurements using the technique reveal correlations between EF and coil currents from different sources. Additionally, the use of a rotating n=1 resonant magnetic perturbation (RMP) offers the advantage of reducing disruption risks by entraining saturated magnetic islands. For ITER-like devices, EF identification using disruption-free plasmas is necessary to minimize potential damage to device walls. These findings are instrumental for optimizing EF correction in fusion devices, thereby enhancing tearing mode suppression and overall plasma stability.

The torque balance model used in this work includes the contribution from electromagnetic (EM) torque due to wall response, error fields, RMP fields, and viscous torque. The magnetic island mode and wall response are measured by the 3D magnetic sensors with consideration of vessel current effects [1][2]. Representing each n=1 field as a phasor (2-D vector) in the horizontal plane, the torque balance contributions from EF, wall, and RMP are determined by the cross product of their phasors with that of the magnetic island, accounting for phase difference and amplitude information. An empirical expression $\alpha \boldsymbol{B}_{\mathrm{m}}^{2}$ is used to quantify the general viscous torque, which has been validated in DIII-D experiments [3]. By fitting the torque balance equation over one or more rotation periods of the RMP, the error field is solved in terms of equivalent RMP coil currents.

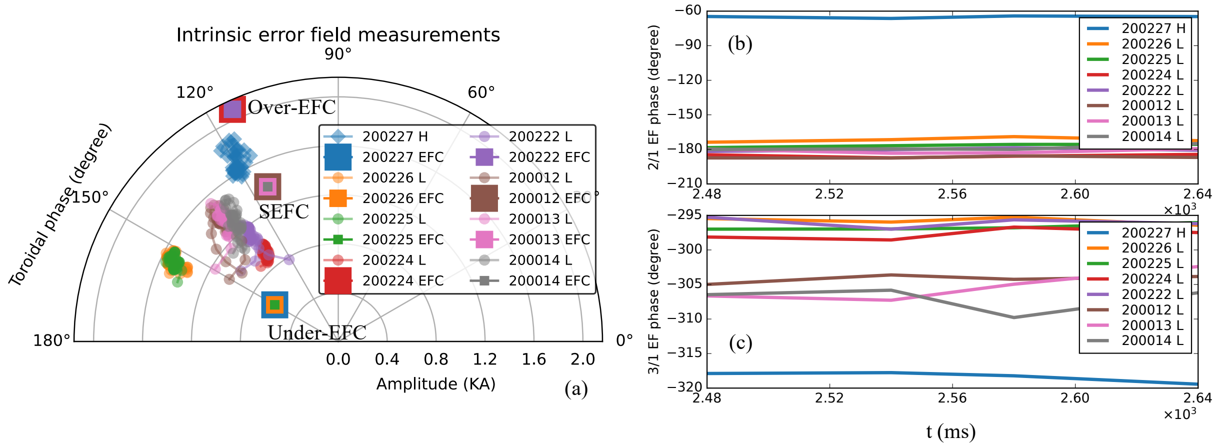

Fig. 1 *(a) Intrinsic EF measurements (circles: L-mode, diamonds: H-mode) obtained through the torque balance approach under three types of EFC (squares) applied by C-coils on DIII-D, and comparisons with SURFMN simulation of EF phase on 2/1 (b) and 3/1 (c) modes produced by shaping coil misalignments.*

The intrinsic EF in ITER-like devices is not known a priori, but this technique shows great robustness in measuring the intrinsic EF amplitude regardless of its amplitude or toroidal phase. Repeated plasma experiments with different levels of error field compensation (EFC) were conducted in DIII-D to create distinct residual EFs. These tests included discharges with the "standard" error field compensation (SEFC) (200012-014) derived from “compass scan” approach [4], as well as over- (200222-224) and under- (200225-227) compensation. As shown in Fig. 1(a), the intrinsic error field measurements, calculated by removing the applied EFC effects from the corresponding measured residual EFs, exhibit consistent results within a reasonable range near the SEFC.

Phase differences in the measured intrinsic EF were observed across various discharges in Fig. 1(a), even with identical currents in the ohmic coils, toroidal coils, and plasma itself. However, shaping coil currents, which respond to plasma control requirements, differed and potentially modify the EF due to coil misalignments [5]. The SURFMN simulation [6] of EF contributions from the shaping coil have shown that the 2/1 mode determines the significant differences between H- and L-modes, and the 3/1 mode presents additional different phase among L-mode themselves. The torque balance measures the overall EF from n=1 modes and shows a combined effect of three types of phase range for the intrinsic EFs. The measurements offered by the technique provide insights into the correlations between EF and coil currents from various sources, and will enable potential scaling of EF based on coil currents.

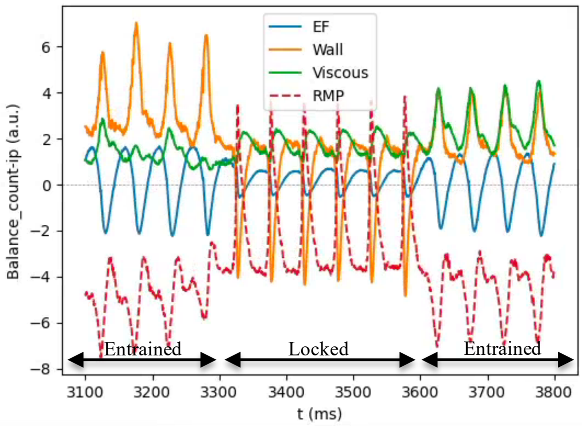

Fig. 2 Torque balance contribution when island rotating with RMP and locked to error field (EF)

Rotating n = 1 RMP fields have been applied using 3D field coils to entrain saturated magnetic islands for measuring the n = 1 error field, which can also reduce disruption risks by stabilizing the plasma against disruptions caused by tearing modes [7]. Figure 2 shows the importance of torque generated by the rotating RMP fields for controlling the rotation of magnetic islands, effectively preventing mode locking, which may lead to disruptions. Initially the magnetic island maintains an oscillatory rotation in the co-Ip direction, staying synchronized with the RMP due to its strong forcing effect. When the RMP coil currents are reduced, the island locks to the residual error field (EF), but without leading to disruption. When the RMP currents are increased, the enhanced torque overcomes the locked equilibrium, enabling the magnetic island to resume rotation.

This technique of torque balance allows for efficient error field identification, offering a valuable tool for scenario-specific and optimized error field corrections. The method requires only magnetic diagnostics, and does not rely on plasma rotation measurements, making it suitable for application during the early commissioning phases of device operations. It also offers the potential advantage of reducing mode locking and related disruptions by entraining saturated magnetic islands.

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