# The Limits and Challenges of Error Field Correction for ITER*

R.J. Buttery[1], Y.Q. Liu[2], J.-K Park[3], N.M. Ferraro[1,4]

*[1]General Atomics, PO Box 85608, San Diego, California 92186-5608, USA*
*[2]EURATOM/CCFE Fusion Association, Culham Science Centre, Abingdon OX14 3DB, UK*
*[3]Princeton Plasma Physics Laboratory, Princeton, New Jersey*
*[4]Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee*

Error fields – non-axisymmetric fields that naturally arise in the design and construction of a tokamak – have long been known to pose a challenge to tokamak operation. Originally, they were considered a limit to low density, low torque operation, and thus a challenge to ITER in its Ohmic phase, prior to H-mode access. An error correction system was specified on this basis [1]. However the realization that the fields interact with the plasma through ideal instabilities [2,3] led to a re-interpretation of effects. In particular, this leads to increasing field sensitivity with β, as the kink mode becomes more readily driven, amplifying the field inside the plasma [4]. It also leads to changes in the correction strategy and spectra of error fields considered to be of greatest concern. As the field will act most strongly through the least stable ideal mode, it suggests that error correction fields tuned to counteract any intrinsic error drive of this mode will do most of the job, by adjusting phase and amplitude of a correcting field that contains a reasonable degree of overlap with this mode.

However, experimentally several devices show that such correction, even when empirically optimized, has limited success. In density rampdown experiments, improvements in limits are typically of order 50% or less, suggesting residual error fields have a strong effect. This suggests that higher order (more stable) ideal modes and/or neoclassical toroidal viscosity (NTV) effects are likely to play a role [5]. Indeed it is likely that correction fields that optimize correction for the least stable mode, may increase drive for higher order modes, or cause residual fields that drive NTV braking. The size of these residual modes and impact of error correction on them is one aspect that needs resolving. Further, given such residual fields, the mechanisms by which the fields lead to magnetic braking (from NTV or various possible resonant surfaces) becomes important, and thus we need to resolve the relative strengths of the various braking mechanisms, and how these are altered by error correction.

These issues are becoming critical to ITER, with recent studies [6] showing that low torque H-mode scenarios are even more sensitive to error fields than the low density Ohmic regimes for which ITER correction was designed; it is possible that ITER will need better than first order error correction, and the requirements and capabilities of this need to be established. Thus, in this paper we review the experimental evidence from many devices of the benefits of error correction, and improvements with better or more correction coil sets. We compare with theoretical concepts to try to deduce how many and which modes and braking mechanisms are playing a role, and contrasting experimental behaviour with the latest numerical calculations. The goal is to engage the theoretical community in a discussion to identify the relevant effects, spur further numerical studies targeted and resolving these issues, and understand critical experimental questions and consequences.

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