GA–A27135

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SEPTEMBER 2011

GENERAL ATOMICS

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This is a preprint of a paper to be presented at the 5th IAEA Technical Meeting on the Theory of Plasma Instabilities, September 5-7, 2011, in Austin, Texas, and to be published in the *Proceedings.*

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Work supported by
the U.S. Department of Energy
under DE-FC02-04ER54698, DE-FG02-04ER54761,
DE-AC02-09CH11466, DE-AC05-06OR23100

GENERAL ATOMICS PROJECT 30200
SEPTEMBER 2011

ABSTRACT

The correction of error fields remains a central issue for achieving high fusion gain in ITER. Great strides have been made in recent years in interpreting error field effects through the plasma's ideal response, and particularly a dominant 'least stable' ideal mode through which the fields couple to the tearing resonant surface. However, experiments have found limited success in correcting error fields, in contrast to theoretical expectations which indicate that cancelling the drive for the least stable ideal mode at the plasma boundary should remove most of the tearing resonant field in the plasma core. Data from several devices indicate a single correction coil array can achieve anywhere between zero and $\sim 50\%$ correction (in terms of operational benefit to a low density locked mode limit), dependent on the structure of the error field and the correction coils. With additional coils up to $\sim 70\%$ is possible. The origins of these 'residual field' effects raises many questions over the nature of field applied and other limitations in the plasma or its control. Thus new studies on the DIII-D tokamak explored correction of a proxy error field, with pure $n=1$ structure at much larger amplitude. These show single coil array correction still limited to a 50% benefit in density limit, and therefore substantial residual effects from the corrected $n=1$ field. This suggests that higher order $n=1$ ideal modes may be significantly driven, potentially changing the balance between possible braking mechanisms. For ITER, updated predictions of field error, compared with revised scalings for tearing mode thresholds, indicate 50% or better error field correction will be needed – likely requiring more than one well positioned coil set. These results set a challenge for theory to model the behavior in order to clarify the plasma response and isolate the braking mechanisms, so that the effectiveness of ITER's correction coils and the possible need for support from its ELM coils can be evaluated.

I. INTRODUCTION

The tokamak is predicated on a toroidally symmetric magnetic field and equilibrium. However in a real device small toroidal asymmetries in the magnetic field naturally arise in its design and construction – for example from the need for current feeds or in construction tolerances. Components of these 'error fields' can resonate with surfaces inside the plasma to drive tearing instabilities, and these have long been known to pose a concern for tokamak operation and a requirement on its construction tolerances.

In a rotating plasma, resonant error fields are mostly shielded out by image currents at rational surfaces, restricting formation of magnetic islands. However, with finite resistivity, this interaction generates an electromagnetic torque [1], which changes the phase of the imaging response from perfect shielding to enable slight tearing. Viscous coupling of this tearing structure to the bulk plasma keeps it out of phase with the error field and suppressed, but if the field is large enough, the electromagnetic torque can overwhelm the rotation leading to a bifurcation to large scale tearing, termed 'penetration', which can ultimately cause a plasma terminating disruption.

These effects pose a particular concern at low plasma density, where decreased viscosity and inertia enables a resonant surface to be slowed more easily, and at low injected torque, which might otherwise help maintain rotation and shielding. They were therefore originally considered to be of greatest challenge for ITER during its low density Ohmic phase prior to H-mode access, with the most performance limiting of such tearing modes found to be of 2/1 structure (denoting by $poloidal/toroidal$ mode numbers as m/n). On this basis, scalings for error field sensitivity were obtained for ITER [2], and an error field correction system designed. This incorporates 3 arrays of field correction coils, in order to be able to independently optimize three $n=1$ low order poloidal field harmonics ($m=1$, 2 and 3), to allow for toroidal and viscous coupling of harmonics resonant with other rational surfaces through to $q=2$.

More recently, however, the realization that error fields interact with the plasma through ideal-MHD instabilities [3,4,5] has led to a re-interpretation of their effects. It is now understood that the internal tearing-resonant fields are created in large part from the plasma ideal-MHD response to the error field – in terms of shielding at resonant surfaces, and perturbed currents associated with a driven kink mode distortion. This has mixed implications. On the one hand, it implies an increasing sensitivity to error fields with rises in β, the ratio of thermal to magnetic field energy, as the kink mode becomes more readily driven, amplifying the field inside the plasma [4,6]. But, it also leads to changes in the spectra of error fields considered to be of greatest concern, and therefore in the required error field correction strategy. In particular, as the error field is expected to act most strongly through the least stable ideal mode (which generally has weaker pitch than the tearing resonant surface), correction fields tuned to counteract the drive for that mode will have greatest benefit.

Based on these concepts, early work on ideal response [5,8] suggested a single strongly dominant eigenstructure for coupling external fields to internal tearing resonant fields, and thus that good error field correction in ITER should be quite straightforward [8]. However, experimental experience has contrasted with this, finding that single coil array correction can have quite limited benefits, highlighting a gap in our understanding. As pointed out in Ref. [6], the limits of error correction will depend on how much and how many secondary ideal MHD modes are driven. It is therefore possible (and perhaps likely) that correction to minimize drives for the primary ideal-MHD mode, might increase drives for secondary ideal modes, leading to a residual field in the plasma and braking or coupling through to tearing resonant surfaces. Further, the structure of the residual field will govern which types of braking (resonances at various rational surfaces or non-resonant braking through Neoclassical Toroidal Viscosity [9]) will apply. Thus, one might envisage suppressing directly resonant 2/1 fields within the plasma, but leaving residual fields elsewhere which might brake rotation and facilitate tearing mode formation [6]. Thus the nature of these braking mechanisms and how they couple through to lead to tearing modes, becomes important, in addition to understanding how the residual field arises and the strength of the various ideal response modes in the plasma. So far the relative roles and strengths of these effects have not been understood.

Thus, critical questions remain for ITER over the performance of its error correction system (designed for low poloidal mode number vacuum fields) and whether other tools are needed, such as the ELM control coils, torque injection, or profile control. As we discuss in Sec. II, threshold scaling and device construction studies indicate that ITER is likely to need significant error field correction. To address how it can go about achieving this, we need to be able to explain existing data in present tokamaks. Thus in Sec. III we review the experimental experience with intrinsic error field correction across many devices. This raises a number of questions about what underlies the residual field effects, and these are explored further with experiments using additional coil arrays to explore mitigation of a known proxy error field at much higher amplitude. The implications of this work for the theoretical understanding, ITER consequences, and further modeling to quantify effects for ITER are discussed in Sec. V.

II. THE ERROR FIELD CHALLENGE FOR ITER

The error field correction system for ITER was originally based on analysis of low m vacuum fields, with a criterion based on an empirical approach for Ohmic regimes [2], updated for the final ITER design in [10]. Error fields were estimated from a Monte Carlo model of possible error field sources, to obtain a prediction of 99% certainty that vacuum calculated fields at the $q=2$ surface, $\delta B_{2,1}/B_T$, would be below 12×10^{-5} (in fact a 3 mode criterion was used, $m=1-3$, but we simplify here). A demanding target to reduce this measure of error field to 5×10^{-5} was set (and met) for the designed correction system (Fig. 1), giving some margin over the expected threshold for the fields to trigger locked modes of $\sim 12\times10^{-5}$ [2]. However, one should note that the error field components now thought to principally govern mode formation (in the ideal response formulation) are actually higher in mode number ($m = 7-9$ at the plasma boundary) [5] than those calculated in the earlier work – thus this formalism represents a rather crude estimate of the correction system requirements.

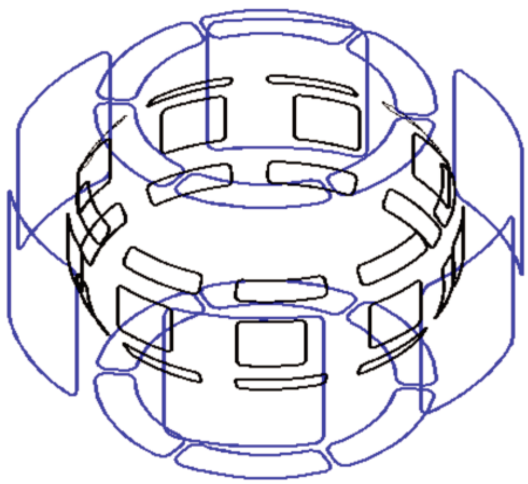

Fig. 1. Schematic of ITER error field correction coils (blue), and ELM control coils (black), which might, if needed be deployed to augment error field correction.

In addition, more recent work [11] has shown error fields pose a greater hazard in H-modes when these are operated at low injected torque (as they will be in ITER). This is of course expected in the ideal response interpretation, as the kink mode becomes more readily driven at the higher β's of H-modes. Further, in H-mode, the error fields, which act to brake plasma rotation, can often destabilize a rotating 2/1 mode (which locks) instead of fully arresting rotation to directly drive a locked mode penetration. This is thought to be related to changes in tearing mode stability with plasma rotation. On this basis, new scalings for mode onset threshold were obtained for the torque free ITER-baseline-like H-mode, though with elevated $q_{95}\sim 4.3$ cf ITER's 3.1. Fields were calculated in terms of the more correctly motivated overlap between the boundary field applied and the ideal plasma mode that couples through to $q=2$ [12], to obtain an expected threshold $\delta B_{overlap}/B_T$ for the ITER baseline of 17×10^{-5} (some 40% lower than the thresholds expected in Ohmic regimes using this method, despite the much higher density of H-mode), and falling further as β rises.

These new H-mode predictions should be compared with expected intrinsic error field levels for ITER, where the Monte Carlo simulations have now been updated for the new formalism of overlap field at the plasma boundary [13]. For the ITER baseline burn scenario, this yields individual contributions from sources such as the solenoid, toroidal and poloidal field coils, test blanket modules, etc., in the range $\delta B_{overlap}/B_T \sim 1\text{–}5\times10^{-5}$ each, with an estimated maximum combined total overlap field of $\delta B_{overlap}/B_T = 28\times10^{-5}$. Thus to stay below the above predicted threshold $\left(17\times10^{-5}\right)$ would require 40% error field correction. But if as expected, thresholds fell further for the lower q_{95} of ITER (the Ohmic scaling is $q_{95}{}^{0.83}$ on DIII-D) then corrections better than 50% may be needed, or higher for higher β scenarios. Thus understanding the relative capabilities of different error field correction coils, is important to determine how to undertake this correction, whether further changes to plasma operation are needed, or if ELM coils are additionally required for error field correction.

III. REVIEW OF PREVIOUS ATTEMPTS AT ERROR FIELD CORRECTION

Error fields or other sources of non-axisymmetric fields have been found to limit operation on several devices (DIII-D [14], COMPASS-D and JET [2], Alcator C-Mod [15], MAST [16]). So far, they have tended to pose the greatest problem at low densities in Ohmic operation, and thus particularly as plasmas are started up – H-modes tend to have high torque and/or plasma rotation, which helps shield out the fields. As a result these devices installed perturbative field coils (typically toroidal arrays of near-identical coils to apply a total field with arbitrary toroidal phase and amplitude) to study behavior and develop correction for improved operational access. In all 5 devices the fields are found to lead to low density limits in Ohmic regimes which scale close to linearly with the strength of applied fields. As a result, the density limit can be used to characterize the strength of a device's intrinsic error field relative to that applied by its perturbative coils, and also of the benefits of intrinsic error correction.

Typically, the required correction field is determined by performing a phase scan of fields from the perturbative coils (Fig. 2). Field amplitude is ramped with a given toroidal phase until a mode forms. This is then repeated with other coil phases. Assuming the same total field (intrinsic + applied) at penetration in each discharge enables deduction of the machine intrinsic error, in terms of equivalent coil currents. Optimal correction is then obtained by applying currents to reach the center of the circle. This approach was confirmed in detailed density ramp-down studies, varying correction currents discharge to discharge in DIII-D [17].

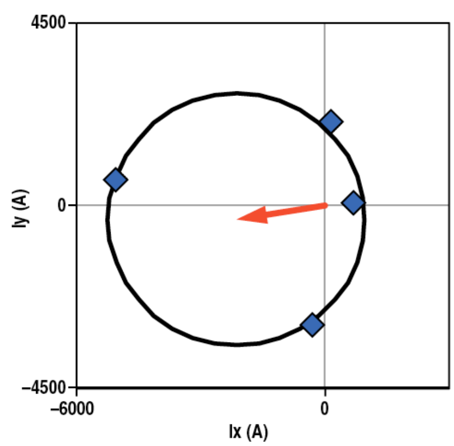

Fig. 2. Measurement of correction field required for an underlying error field. Thresholds for locked modes are measured with field ramps for four phases of the correction coil (diamonds), and fitted by a circle to determine the optimal correction field amplitude and orientation (arrow). (In fact the error field measured here is the proxy error field source described in Sec. IV).

When applying error field correction in this way, two key observations come to light. Firstly it is found that the degree of correction obtained, as measured by the improvement in the low density locked mode limit is quite limited. Whilst lower densities can be accessed with error correction, a clear limit is still obtained, indicative of a substantial residual field effect. Second, that the degree of correction obtained is quite variable, dependent on the device and the nature of the coil sets deployed for field measurement and correction. Given the significance of these results, it is worth summarizing in more detail.

The earliest work came from DIII-D [14], where it was found that a single '$n = 1$' correction coil located above the plasma (Fig. 3) could enable access to $\sim 25\%$ lower densities. This had limited benefit perhaps because of the fixed location (i.e. phase) of this single coil. But further work [17] utilizing an array of ex-vessel midplane 'C-coils' showed improvements in density limit of 40-55%. The degree of benefit, and currents required for optimal correction, depended on the plasma regime and magnetic field structure of the plasma (safety factor, q_{95}). Further it was found that combining "C-coil" array correction with the $n = 1$ coil led to even better error correction ($\sim 70\%$ improvement). This appears to be direct evidence that correction field structure matters greatly to the degree of correction achievable. In the ideal-response interpretation it also indicates that secondary (and perhaps tertiary) ideal response modes must be playing a significant role. Finally it was found that the installation of further 'I-coils', internal arrays above and below the outboard midplane, led to improved density access compared to the C-coil correction, confirming that field structure matters. Indeed, it is found that correction field structures most closely aligned to the kink mode structure (rather than field line pitch resonant) give the strongest plasma response, most easily trigger rotation collapse to locked mode [5], and require less currents for error field correction [18].

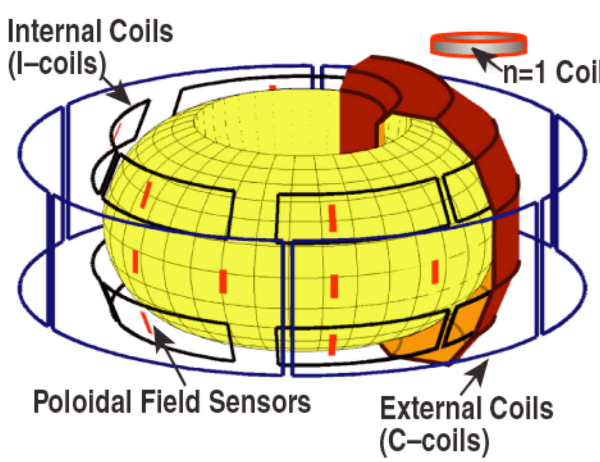

Fig. 3. Coils used in the DIII-D Error Field Experiments.

These observations are corroborated by other devices. On JET [19] internal saddle coils, with toroidal bars located below the plasma either side of the divertor region, led to a 40% reduction in operational density limit when used for error field correction. Crucially this was good enough correction for tearing modes to unlock, start rotating and decay away. However, when the experiments were repeated with a new coil array [16], the "Error Field Correction Coils" (EFCCs) located ex-vessel on the outboard midplane, the variation in thresholds to induce tearing modes between different phases of EFCC was found to be negligible, and so no correction improvements were possible (despite there being no known changes made in the underlying JET intrinsic error). The result is interesting because it demonstrates that a coil set that clearly does couple to the plasma and is able to induce tearing modes (the EFCCs), can generate fields that are effectively orthogonal to another source of field (the machine intrinsic error). This would appear to indicate more than one mechanism or mode to couple the fields through to the plasma and trigger tearing, with the two field sources here generating quite different mixes of these. It also highlights the fact that the wrong type of correction coil design may offer little benefit for tearing mode avoidance.

However, a similar ex-vessel midplane coil on the spherical tokamak device, MAST, did lead to significant benefits in locked mode density threshold (at least 30%, with no tearing modes found at this density) [20]. Finally, on C-Mod a set of two toroidal arrays of four vessel mounted coils, located above and below the midplane, were found to lead to significant operational improvement, with up to ~ 60% lower density access [15]. Like the DIII-D I-coils, this seems to confirm that poloidally separated pairs of toroidal coil arrays can be more effective at error correction, perhaps because they are better at cancelling out some of the stray harmonics in the plasma and applying a 'purer' mix of the right harmonics?

Reviewing this data it seems clear that correction from a single coil array can achieve anywhere between zero and 50% improvement in terms of the error field's effect on locked mode density threshold. The benefits seem to depend on structure of coils and indeed of the plasma, but can be improved further by combining additional coil sets. The results highlight substantial roles associated with residual fields and (in the ideal response interpretation) secondary ideal modes through which the coils couple to the plasma. These observations, all obtained with $n=1$ coil configurations indicate that is likely that $n=1$ is the dominant toroidal harmonic to consider. Nevertheless it is also possible that some residual effect may come from higher n components. However, the results summarize here are hard to analyze cleanly, because they all involve relatively poorly known intrinsic error fields.

IV. TESTING THE PHYSICS OF ERROR FIELD CORRECTION WITH A KNOWN PROXY FIELD

There has been much speculation over the origins of the limits of error field correction in accessing low density – suggested to arise from unknown field components, additional NTV effects, higher n fields, or even control problems. To explore this in a controlled, and model-able manner, dedicated experiments were formulated on DIII-D, using its unique multiple coil arrays (Fig. 3) to generate a proxy $n=1$ error field with one coil set (the 'C-coils') and then attempt correction with a second array (the 'I-coils'). These coil sets have dramatically different field structures (see Fig. 4), as is usually the case in intrinsic error field correction. Thus experiments could explore correction of a known, large dominant proxy error field with pure $n=1$ structure, at much higher operational density than traditional studies.

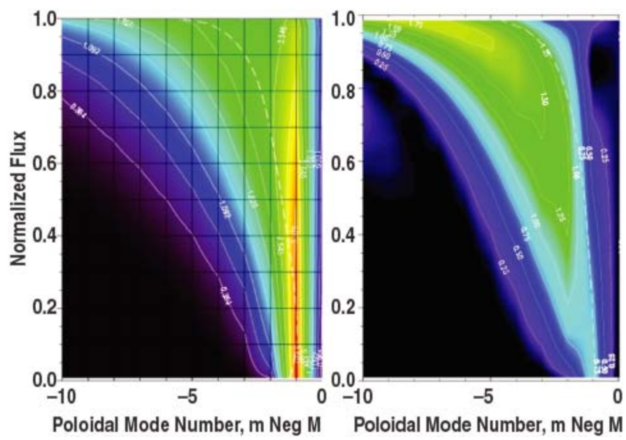

Fig. 4. Comparison of field spectra C-coils (left) and I-coils (right): Color indicates field strength (arbitrary scales) for a given poloidal harmonic (x value, negative for relevant plasma helicity) and radial location (y value). The C-coils make a much more core localized perturbation, while the I-coils make a field most resonant with higher mode numbers nearer the edge of the plasma.

Discharges were obtained by first ramping the density to a high value to then enable application of a significant amplitude C-coil proxy field without inducing tearing modes. I-coils were then ramped with various relative phases to the C-coil field to measure the optimal correction field. I-coils were deployed with the usual 240 deg toroidal phase difference between upper and lower arrays, found optimal for intrinsic error correction on DIII-D, and best aligned with ideal MHD modes [6]. A subtlety of the experiment was that the phase scan was performed by rotating the source C-coil field phase (with fixed I-coil phase throughout), rather than the I-coil phase. This meant that the I-coil phase scan measured just the proxy field, and not the machine intrinsic error. To reduce uncertainties from machine intrinsic error field, a phase scan of C-coil current ramps was performed prior to the I-coil experiments, to deduce the C-coil currents that minimize machine error. These were applied as offsets to the C currents used to generate the proxy fields in the main experiment. Finally, in the main experiment the I-coil phase (which was kept fixed, as noted above) was chosen to be orthogonal to the measured machine error and its correction by C-coils, in order to minimize the effects of any inaccuracy in the correction optimization.

A typical experiment is shown in Fig. 5. During a density ramp-up C-coils applied the above-described intrinsic error correction. Once high density was reached, C-coils were switched to apply the additional proxy error field with 2kA peak amplitude and an $n=1$ sinusoidal distribution in toroidal angle. I-coils were then slowly ramped to determine the level that induces a static tearing mode, as observed by a pair of toroidally opposite saddle loop detectors. The resulting $n=1$ I coil currents at mode penetration are those of Fig. 2, where the vector orientation of points represents the phase of the I-coil field relative to that of the applied C-coil proxy field (taking I-coil phase as the average between upper and lower coil orientations). Fitting with an offset circle, it is found that optimal correction of the proxy error is obtained with 2.2kA amplitude currents in the I-coils, and at a phase of 171 deg – close to perfect opposition to the C-coil proxy field (a small difference might be expected as fields are structured differently and so might couple differently to the plasma; there is also a natural scatter in the data). This I-coil correction field was then applied to density ramp-downs with proxy field still deployed, to determine the benefits of correction.

To obtain useful results from these experiments, sufficient headroom in density had to be generated to enable application of the proxy field and optimization of its correction at levels well above those associated with the corrected intrinsic error. However, density had to be not so high as to require I-coil currents in the phase scan to exceed power supply limits (6.3kA). The parameter space is summarized in Fig. 6. Considering first the underlying intrinsic error, the density ramp-down in discharge 144428 captures the locked mode threshold with uncorrected intrinsic error field, 0.95×10^{19} m^{-3}. However, with re-optimized intrinsic error correction from the C-coils, this was reduced to 0.44×10^{19} m^{-3} – a good level of correction (and an improvement from the previous C-coil correction algorithm, which was found to only reach 0.72×10^{19} m^{-3}). This re-optimized correction, required currents of up to 500A in the C-coils, and this was used as the basis for the proxy field studies.

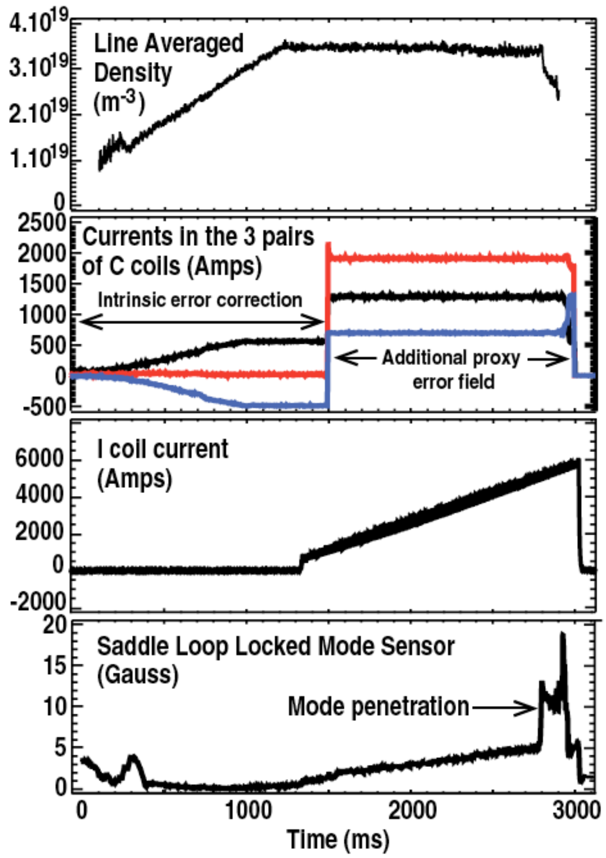

Fig. 5. Example of proxy error field experiments. C-coils are deployed for error field correction before proxy field is added. I-coils are then ramped up to measure locked mode threshold.

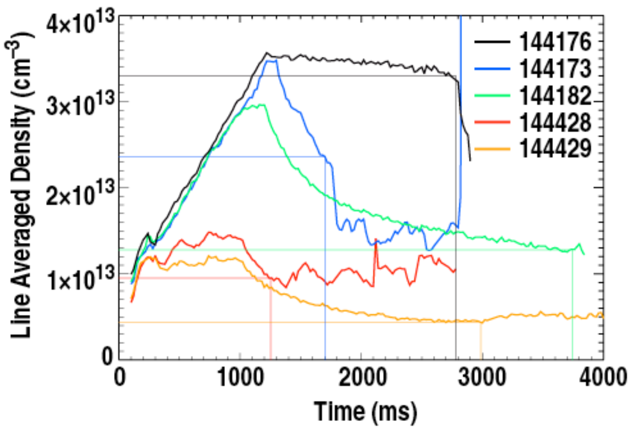

Fig. 6. Operational space of proxy error field experiment, with mode onset times and densities marked by correspondingly colored straight lines. In order of decreasing locked mode density: constant density discharge with proxy field and I-coil ramp (black, #144176), and density ramp-downs with proxy field applied (blue, #144173), I-coil-corrected proxy field (green, 144182), machine error only (red, #144428), C-coil-corrected machine error (orange, #144429).

Thus to gain sufficient headroom for a dominant proxy field experiment 2kA of proxy field were applied with the C-coil and an operational density of $\sim 3.4 \times 10^{19}$ m^{-3} was chosen for the phase scan. Limiting the proxy field current to 2kA gave sufficient headroom for the phase scan, where (Fig. 2) considerably higher I-coil currents were required to measure opposing phases. The dominance of the proxy field over the corrected intrinsic error field is indicated in Fig. 6: a density ramp-down with the proxy field applied led to a density limit of 2.46×10^{19} m^{-3} (averaging two discharges) – well above corrected intrinsic error limits, while using I-coils to correct this proxy field, lowered the density limit to 1.28×10^{19} m^{-3} – still significantly higher than the corrected intrinsic error field which gave a locked mode density threshold of 0.44×10^{19} m^{-3}.

This immediately indicates that the I-coil correction of the proxy field still leaves a large residual field, substantially larger than the corrected intrinsic error, that can couple to induce tearing modes. This residual field must have $n = 1$ structure – higher n fields are eliminated as an origin of residual effects, as these are negligible thanks the symmetry of the I- and C-coils deployed. To better quantify the degree of proxy field correction obtained, one needs to allow for the residual corrected intrinsic field. This can be estimated by using density thresholds as a measure of field amplitude (noting the linear relation generally observed). If one considers that the proxy field was applied at 90 deg to intrinsic error and correction fields, and also that it is likely comprised of a different harmonic mix, it would seem reasonable to consider the C-coil corrected intrinsic error field and proxy fields to be reasonably orthogonal. Thus the total field leading to a locked mode can be considered as the sum of these two components added in quadrature, as discussed in Ref. [11]. Recalling the proportional relationship generally observed between locking density and perturbation field amplitude, gives the expected density limit from the underlying corrected proxy field (excluding contribution from corrected intrinsic error) as $\surd(1.28^2 - 0.44^2) = 1.20 \times 10^{19}$ m^{-3}, compared to that of the uncorrected proxy field (also excluding contribution from corrected intrinsic error) of 2.42×10^{19} m^{-3}.

Thus the correction field has removed $\sim 50\%$ of the operational effect of the proxy field – a strong $n = 1$ field remains that couples through the plasma to induce a tearing mode. In the ideal response interpretation, this indicates that the higher order ideal modes through which an $n = 1$ field couples must have significant amplitude. The challenge now lies to explain both the strength of this response, and where these residual fields lie in the plasma and what sorts of braking they might lead to. This is naturally a task that can be further advanced using the modeling tools described earlier in this paper, constructing cases of proxy field correction, looking at the strength of the ideal plasma response, and calculating the various types of braking (resonant at various surfaces, and NTV braking) to identify a significant possible source of the interaction.

V. DISCUSSION

The obvious question arising from these observations is "what do they imply for the mechanisms by which error fields couple to the plasma?" The proxy experiment confirms that the residual field effects are strong manifestations of the error field physics – not control or operational limits from other processes, and not arising from higher n components (though these could in principle pose additional challenges). They show that even for pure $n=1$ fields, correction is limited (here to the $\sim 50\%$ level), and that therefore the fields must be coupling to the plasma through more than a single dominant ideal mode – perhaps, either a secondary ideal mode of similar strength (i.e. stability) to the first, or a number of weaker ideal modes that add up to the same effect. It is also possible (and indeed likely) that the residual field might couple to the plasma through a different mix of resonant surfaces and/or non-resonant effects than for the uncorrected error field. Further, if calculations indicate that these secondary ideal modes are expected to be much weaker, then this suggests that the particular residual field arising from error field correction might be localized to a structure and region of the plasma that is more sensitive to field effects and more readily able to lead to tearing.

As discussed in Sec. IV, the action now lies with modeling to explore these possibilities. However further clues can be gleaned from the wider experience of error correction. The limitations in single array correction corroborate a strong role of residual fields and secondary ideal mode responses. Indeed, even with two sets of correction coils, DIII-D found limited benefits, hinting that further (tertiary) ideal modes may play a role, or simply, that it is not that easy to null out fields in the plasma. As correction fields are added in to null out drives for the dominant ideal mode (which in turn couple directly to $q=2$), this correction may drive further combinations of ideal modes that lead to localized increases in fields elsewhere. On this situation effects such as NTV, which are volume integral and additive may play a stronger role. Perhaps the most interesting result is the lack of effective correction with EFCCs on JET – where despite these coils being able to couple to the plasma and readily trigger tearing modes, they had almost no operational benefit for intrinsic error correction and seemed to act entirely orthogonally to the JET intrinsic error field. This is a strong indicator of more than one mechanism or mode through which the fields can couple to the plasma.

For ITER these limits suggest that it will need to deploy more than one correction coil set, unless behavior is favorably impacted by an anomalous strong rotation source. It also shows that the shape of the coil set (and intrinsic error) matters. Without a full understanding of the effects described here, it is impossible to make hard numerical predictions of the effectiveness of its correction systems. Nevertheless one might empirically conclude as follows: ITER's midplane coils offer significant potential (0-50%

correction?), but likely the benefit will depend on the exact nature of the underlying error field. Recent revised ITER error field estimates [13] suggest predicted error fields in ITER will be significantly larger than new low torque H-mode scaling measurements of error field threshold [11], with sensitivity further enhanced at ITER's low q_{95} or with rises in β, potentially raising demands for error correction well beyond the 50% level. Thus further coil arrays are likely to be needed. Experience from DIII-D shows that the top (or bottom) coils may improve the situation somewhat – though the amount of benefit remains uncertain, with these coils being poorly located for resonance with the kink instability. If these do not prove enough then it is likely that the ELM coils would provide the additional flexibility to do significantly better correction, noting the benefits of coil pairs and/or coils close to the plasma on DIII-D, C-Mod and JET. Thus for the time being ITER should retain the option to deploy error field correction with its ELM control coils. It is now incumbent on the community to understand these processes better and put this correction on a firmer footing.

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ACKNOWLEDGMENT

This work was supported in part by the US Department of Energy under DE-FC02-04ER54698, DE-FG02-04ER54761, DE-AC02-09CH11466, and DE-AC05-06OR23100.