Passive deconfinement of runaway electrons using an in-vessel helical coil

D.B. Weisberg1, C. Paz-Soldan1,2, Y.Q. Lin1, A. Welander1, B. Lyons2, C. Dunn3
1General Atomics, 2Columbia University, 3Georgia Tech.
weisbergd@fusion.gat.com

ABSTRACT

• Numerical modeling of a helical coil designed to passively generate non-axisymmetric fields during a plasma disruption shows efficient deconfinement of runaway electrons (RE).

• Optimization of coil geometry is performed using TokSys1 electromagnetic analysis of inductive coupling during current quench (CQ), and SURFMN2 vacuum island overlap width (VIOW) generated in experimental equilibrium.

• Relativistic drift orbit tracing using the linear MHD code MARS-F,3 predicts up to 70% of RE orbits lost after 200μs.

BACKGROUND

• REs are an existential problem for high-current tokamaks, have kinetic energy in the tens of MeV range, and can seriously damage hardware.

• Previous studies4,5 have demonstrated the feasibility of deconfinement via the application of 3D fields.

• A proposed in-vessel helical coil would inductively couple to the disruption current quench and generate a large 3D field to limit RE formation. Ideal tokamak models have defined thresholds for coil current and field3:

\[ \frac{t_{\text{oin}}}{t_{\text{ov}}} \geq 2\% \]

\[ \frac{\delta B}{B_0} \geq 10^{-2} \]

• This study investigates the parametric optimization of an in-vessel helical coil as a passive safety measure against RE beam formation.

OPTIMIZATION WORKFLOW

COIL PARAMETRIZATION

The helical coil geometry is defined by three parameters (Fig. 1): 1. Pitch angle of centerpost helix (θ0 = height of n=1 helix)

2. Discrete number of vertical helix segments (nax)

3. Absence/presence of poloidal outboard loop

VACUUM FIELD OPTIMIZATION

An RE mitigation coil must minimize the inductive coupling with the plasma current as well as the magnetic coupling to the plasma equilibrium. TokSys and SURFMN are used to calculate two vacuum field metrics over a range of coil geometries:

1. Non-resonant mode amplitude on magnetic axis \( \delta B_{\text{pol}}(n) \)

2. Resonant vacuum island overlap width (VIOW: from plasma edge inward)

Two mid-elliptic RE equilibria from RE-forming experiments on DIII-D are used as test cases (Fig. 2), with high-\( I_p \), \( q=2.4 \) and low-\( I_p \), \( q=4.8 \).

RELATIVISTIC DRIFT ORBIT TRACING

Based on the vacuum field results, several coil geometries are selected for analysis in MARS-F. The full plasma response is calculated, and orbits of an initial distribution of relativistic test particles are traced. The loss fraction of RE orbits is compared between coil geometries and equilibria.

ACKNOWLEDGEMENTS / REFERENCES

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, using the DIII-D National Fusion Facility, a DOE Office of Science user facility, under Awards DPC02-04ER54696, as well as by internal General Atomics funds.

REFERENCES