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Understanding and avoiding disruptions that halt fusion reactions

New supercomputing capabilities help understand how to cope with large-scale instabilities in tokamaks

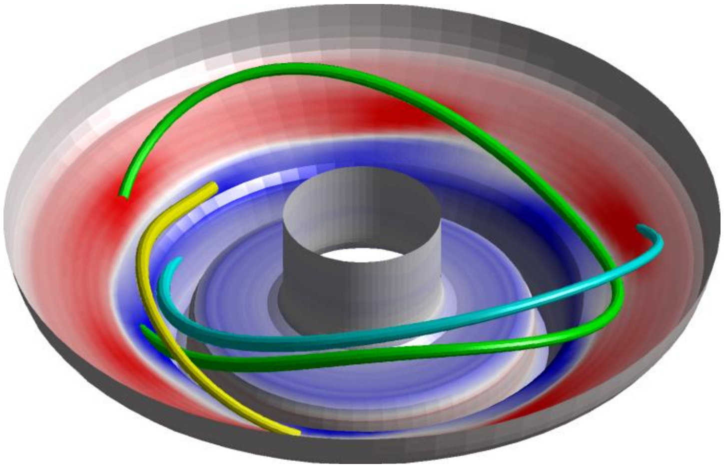

Image courtesy of David Pfefferlé (PPPL).
A cutaway of the lower divertor region of NSTX in a simulation of a disruption. The red and blue colors indicate electrical "halo" currents into the walls of the tokamak. The rope-like structures show the paths of three magnetic field lines that intersect the walls.

The Science

Tokamak disruptions are large-scale instabilities that cause rapid and complete loss of magnetic confinement in fusion experiments. Models of fusion plasmas now combine advanced numerical methods with high-performance computing capabilities to explore the causes and dynamics of disruptions in unprecedented detail.

The Impact

Disruptions pose one of the most significant challenges to designing a fusion reactor. During these events, electrical currents arising in the walls create significant forces that can damage the walls of the tokamak vessel. New capabilities to model these currents in fully three-dimensional geometry, with realistic plasma parameters, can lead to strategies that avoid and mitigate disruptions in future reactor-sized devices.

Summary

The tokamak is an efficient design for confining superheated plasmas with magnetic fields because much of the magnetic field is produced by electrical currents in the plasma. This advantage can become a liability, since perturbations to the plasma current can reduce the magnetic field in a self-reinforcing cycle, causing rapid loss of confinement. Moreover, these disruptions impose strong electromagnetic forces and heat loads on the tokamak vessel, posing a major challenge to successful operation of a tokamak reactor.

Researchers are now carrying out fully three-dimensional simulations of large-scale instabilities in the NSTX and DIII-D tokamaks. These simulations use the M3D-C1 code, which models the plasma as an electrically conducting fluid. New high-fidelity capabilities in the code show the electrical “halo” currents that can lead to disruptions flowing into and through the walls of the tokamak. And further simulations of vertical displacement events (VDEs), which often cause or accompany disruptions, show that violent secondary instabilities may develop as the plasma is pushed against the vessel wall.

These secondary instabilities generally lead to a three-dimensional distribution of halo current, which consists of symmetric and asymmetric components. Asymmetric currents may produce forces that are particularly damaging to the tokamak vessel. Fortunately, in these simulations the asymmetric component remains localized and strongly subdominant to the symmetric component, even in cases that exhibit a strongly growing secondary instability. The simulations also show that cooling the plasma before or during the VDE may further suppress the instabilities that lead to asymmetric current. Future work will model disruptions initiated by other instabilities in which the asymmetric component of the halo currents is expected to be larger.

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Publications

N.M. Ferraro, S.C. Jardin, L.L. Lao, M.S. Shephard, and F. Zhang, “Multi-region approach to free-boundary three-dimensional tokamak equilibria and resistive wall instabilities.” *Phys. Plasmas* **23**, 056114 (2016); doi: http://dx.doi.org/10.1063/1.4948722

D. Pfefferlé, N. Ferraro, S. Jardin, A. Bhattacharjee, “Fully 3D modeling of tokamak vertical displacement events with realistic parameters.” APS Division of Plasma Physics Meeting, abstract GP10.086. San Jose, CA (2016).