April 2017

Exploring the Effect of Rotation on Tokamak Plasma Response to Three-Dimensional Magnetic Perturbations

Suppressing edge localized modes with three-dimensional magnetic perturbations in ITER will require a means to control the edge electron rotation.

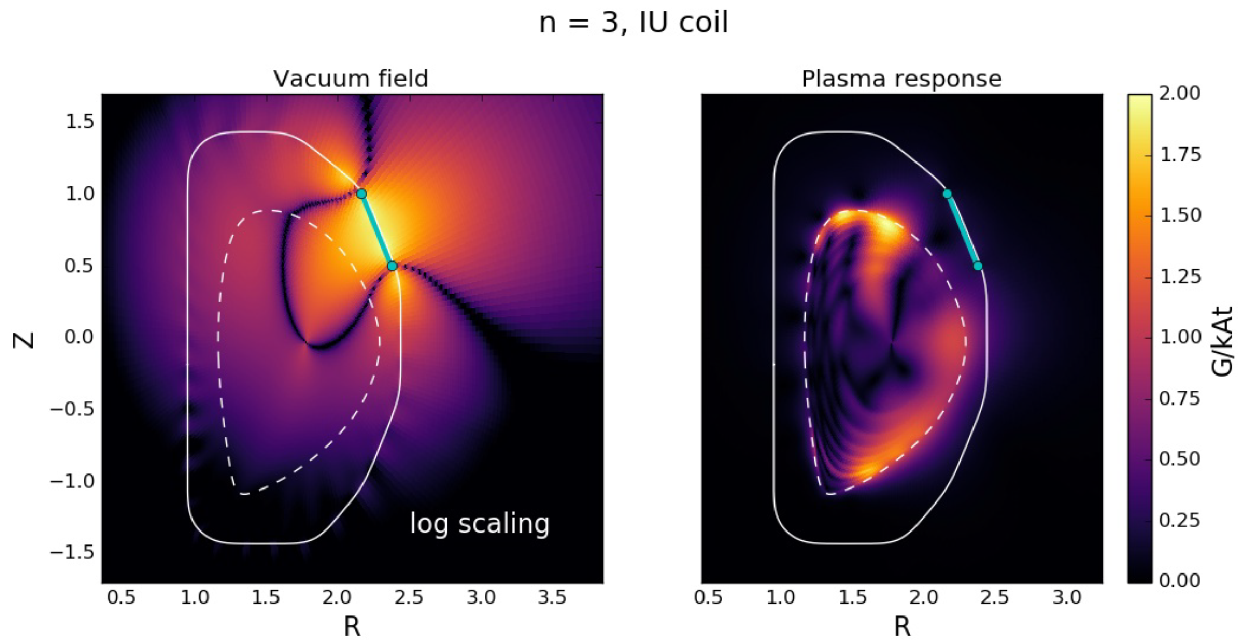

Image courtesy of D. Weisberg, General Atomics
Calculations using the MARS-F code of (left) the applied magnetic field perturbation on a log scale, and (right) the resonant part of the magnetic field generated by the plasma in response to the perturbation, plotted using the linear scale on the right of the figure. The plasma response field on the right varies with position in the plasma cross section, indicating that the extent of the plasma screening of the perturbation varies as well. The solid white line indicates the device wall, and the dashed white line indicates the boundary of the plasma confined in the device.

The Science

The natural response of a plasma to an externally applied magnetic field is to produce electron currents in the plasma that screen out the applied magnetic field. This screening response requires that the electron rotation perpendicular to the confining magnetic field be finite. Consequently, plasma theory predicts that this screening response will break down wherever the electron rotation perpendicular to the magnetic field is small. This prediction has been verified in a series of experiments in which the electron perpendicular rotation profile was varied in a controlled manner, and the plasma response to the magnetic field perturbations was explored. Verifying the predictions of this plasma theory are important for understanding how to use such small (1 part in 10,000) magnetic perturbations to suppress edge instabilities in next-step burning plasma devices such as ITER.

The Impact

Next-step burning plasma devices, such as the ITER tokamak currently under construction in France, need a method to suppress the periodic edge instabilities that can expel up to 20% of the plasma heat in short bursts that are reminiscent of solar flares, and which damage the device wall. Small (1 part in 10,000) three-dimensional magnetic perturbations in existing devices suppress these bursts when the plasma screening response to the perturbations breaks down near the plasma boundary. This breakdown is predicted to occur near the radius where the electron rotation perpendicular to the confining magnetic field is nearly zero. Since the electron rotation in ITER is anticipated to be low compared to existing devices, successful control of these heat bursts in ITER will require a method to adjust the electron rotation perpendicular to the magnetic field in order to place the point where the magnetic field perturbations penetration the plasma sufficiently close to the boundary to suppress the heat bursts.

Summary

Achieving net fusion power output requires operation in a high confinement state known as H-mode. While H-mode operation provides many benefits, it also leads to large edge plasma pressure and current which drive repetitive magnetohydrodynamic (MHD) instabilities known as “edge localized modes, or “ELMs.” In next-step tokamaks such as ITER, these ELMs are predicted to expel up to 20% of the heat in the plasma in short bursts, similar to solar flares, that can damage the device walls. Consequently, it is important to suppress these bursts in ITER. At the DIII-D tokamak, a technique to suppress ELMs, invented in 2003, uses small (1 part in 10,000) perturbations to the magnetic field that confines the plasma in order to degrade the plasma confinement in a narrow region in the plasma boundary. The plasma response to the applied magnetic perturbations is to generate electric currents that screen out the perturbation, and in theory this happens wherever the electron rotation perpendicular to the confining magnetic field is sufficiently large. However, where this rotation is low enough, the screening is predicted to fail, and the magnetic perturbations penetrate the plasma, leading to enhanced transport. If this point where the screening response breaks down occurs close enough to the plasma boundary, the resulting increased transport reduces the edge pressure and current, leading to suppression of the ELMs and their associated heat bursts. A series of experiments have been conducted in the DIII-D tokamak to vary the electron rotation in controlled ways to explore this transition from a screened to a penetrated plasma response, and the results have been compared to the predictions of the MHD plasma response model. The results confirm the dependence of the plasma response on the electron rotation, and the need for the magnetic perturbation penetration to occur sufficiently close to the plasma boundary in order to suppress ELMs. These results indicate that suppressing ELMs in ITER, where the electron rotation is predicted to be lower than in present devices, may require a means to control the location of the null in the electron rotation.

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Publications

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April 2017

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