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The plasma bear trap: General Atomics research on taming edge instabilities in helium plasmas to enhance ITER safety

Scientists at General Atomics (GA) have discovered how to control potentially damaging eruptions of hot plasma in tokamak fusion machines, a discovery that could help pave the way for the future of clean fusion power.

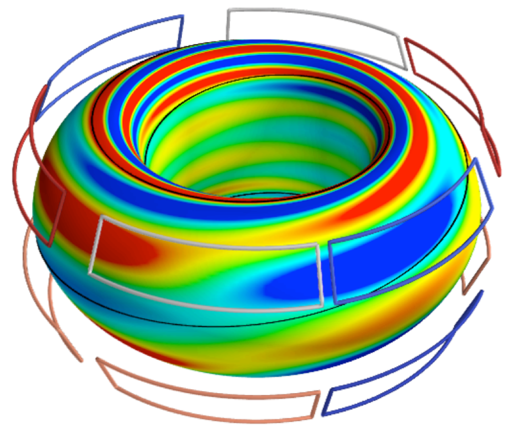

Figure 1 – Keeping energy-producing plasma in control: Simulated plasma response to 3-D perturbation coils on DIII-D produced using IPEC. Courtesy of Nikolas Logan/Princeton Plasma Physics Lab

GA physicist Dr. Todd Evans likens the taming of these eruptions in the plasma to "tickling a sleeping bear without waking it and being mauled or seriously injured."

This control will be required to safeguard the superhot plasma to be produced in ITER, the massive fusion energy machine now being built by an unprecedented scientific partnership of 35 nations.

The challenge is that high-performance fusion plasmas require very large edge densities and temperatures, with conditions that allow the temperature to drop by about a factor of 1,000 near solid machine surfaces only a few centimeters outside the plasma edge. These conditions result in uncontrolled eruptions of the plasma edge (called Edge Localized Modes or ELMs) that release large amounts of plasma particles and energy similar to eruptions seen on the surface of the Sun.

Such uncontrolled eruptions could damage the vessel walls of a tokamak the size of ITER , which will be the largest energy-producing fusion device ever built. Its design is four times the size of the DIII-D National Fusion Facility, which is the nation's largest tokamak and operated by GA for the Department of Energy.

Recent experiments in the DIII-D have proven that ELMs can be controlled and even completely eliminated. This important discovery came in deuterium plasmas using a novel set of 3-D magnetic perturbation coils located inside the vacuum vessel behind protective carbon tiles several centimeters outside the plasma [see figure 1]. These perturbation coils produce magnetic fields approximately 10,000 times smaller than the main magnetic field used to confine the hot plasma. The magnetic fields from the coils produce a helical response at the plasma edge, as shown in figure 1, that alters the frequency and size of the ELMs, which is called mitigation, or completely eliminates the ELM eruptions, known as suppression.

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GENERAL ATOMICS

(From P-1)

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In helium plasmas, such as those being considered during the first few years of operations in ITER to avoid producing energetic neutrons, these DIII-D experiments have shown that ELM suppression can result in unexpected transitions from high confinement (H-modes) to low confinement (L-modes) if not done carefully. These transitions need to be avoided in ITER because they could result in a loss of plasma position control that would allow the plasma to hit the vacuum vessel wall and cause significant damage.

Results from recent DIII-D experiments in helium plasmas are shown in Figure 2. The upper part of the figure shows the timing of the current in the 3-D coils that produces the small magnetic perturbation fields and the evolution of the plasma density during an initial H-mode stage with high heating power and plasma rotation. During this initial H-mode stage the large spikes seen on the ELM signal in the lower part of the figure are caused by the ELM eruptions. At 1900 milliseconds (ms) the heating power is reduced and the rotation slowly drops. During this time the density increases somewhat while the ELM eruptions become smaller and less frequent. This is followed by a transition to an L-mode where the plasma confinement is degraded and the density drops. After a few hundred ms the H-mode is recovered and the ELMs are completely eliminated. Based on these experiments a new approach has been developed to control the power radiated by the plasma that avoids these L-mode transitions which can be applied in ITER.

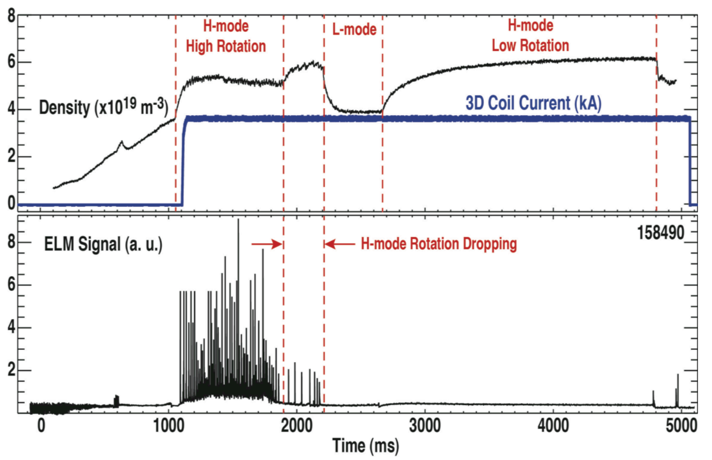

Figure 2 – (Upper panel) plasma density and 3D coil current, (Lower panel) spikes seen on the ELM diagnostic showing the elimination of ELMs in a low rotation helium H-mode plasma.

The DIII-D results suggest that ELM control during helium plasmas in ITER may be a delicate balance between aligning the 3-D perturbation field to suppress or mitigate ELMs while avoiding L-mode transitions that may damage the ITER walls, similar to tickling that sleeping bear without waking it using the approach developed at DIII-D.

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Abstract:
TP12.00100 ELM suppression in high-purity DIII-D helium plasmas Session Poster session VII, DIII-D II