A Little "Magnetic Chaos" Relieves Tension in the Plasma Boundary

As tokamak performance levels are pushed upward toward those needed in future fusion reactors, the edge plasma pressure builds up to an extraordinarily large value. At the magnetic boundary, where the pressure drops by more than a factor of ten over a very narrow region, instabilities known as Edge Localized Modes (ELMs) periodically expel particles and energy, thereby relieving the tension in the magnetic field set up by high plasma pressure. While ELMs are beneficial for controlling plasma density and expelling impurities that contaminate the reactor fuel, they also represent a threat to the lifetime of the wall components used to exhaust fusion power. The impact ELMs have on the power exhaust systems is quantified by the energy released ΔW_{ELM} during the rather short ELM pulse. Recent studies on the nature of ELMs indicate that ΔW_{ELM} increases as the edge plasma pressure increases and as the collision probability between plasma particles decreases. In a fusion reactor the edge plasma must have a high pressure and a low collision rate, implying that ELMs would be very virulent.

In a series of pioneering experiments done on the DIII-D tokamak last year, researchers have discovered that ELMs can be reduced, in some cases eliminated, by introducing a small amount of magnetic chaos across the edge with simple magnetic perturbation coils. Previous DIII-D experiments with edge magnetic chaos in plasmas with high edge collision rates only partially eliminated ELMs. An example of the chaotic magnetic field structure is shown in Fig. 1. A normal nested magnetic structure would be seen as straight, unbroken horizontal lines. This "magnetic chaos" increases the edge particle loss and keeps the plasma pressure just below the threshold for triggering ELMs. More importantly, the energy loss of the plasma does not change much and the edge plasma temperature actually increases, which is important for improving the performance in fusion reactors. In addition, the increased particle loss provides improved plasma density control and helps flush out impurities from the vacuum vessel walls.

These results are surprising because chaotic magnetic field transport theory predicts that the energy loss rate should increase much faster than the particle loss rate. Although theoretically challenging, these experiments provide a very promising outlook for the development of ELM control scenarios in future fusion reactor experiments such as ITER, since the magnitude of the particle loss rate is controlled by the amount of current in the coils producing the magnetic chaos. Even more promising is the fact that the effectiveness of the chaotic region increases as the probability for collisions drops. Comparing DIII-D ELM control experiments done in plasmas with low and high collision probabilities, we find that the edge magnetic chaos reduces ΔW_{ELM} significantly in both cases. In the case with low collision probability, approximately equal to that expected in ITER, ELMs are virtually eliminated for times long compared to thermal equilibration times (as long as the experimental hardware allows).

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Contacts: T.E. Evans, General Atomics, (858) 455-4269, evans@fusion.gat.com
T.S. Taylor, General Atomics (858) 455-3559, Tony.Taylor@gat.com

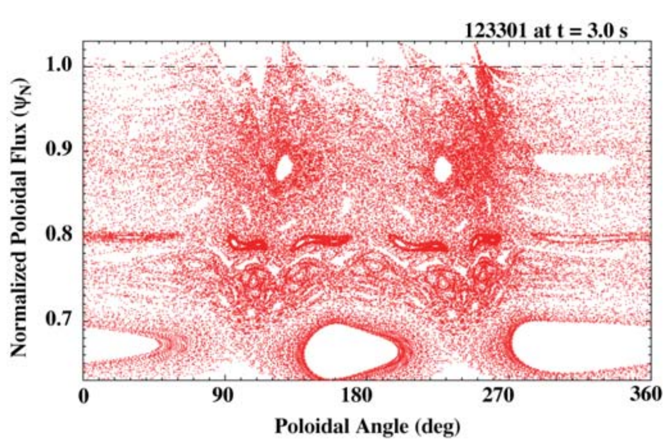

Figure 1. Chaotic magnetic field lines are shown as a pattern of red dots in this Poincare plot, which indicates their radial location (vertical axis) versus the poloidal angle (horizontal axis). Dots that cross the boundary (dashed line) hit the tokamak walls. The large white regions are called magnetic islands, where the magnetic field is not chaotic.