Pushing the Pressure Envelope with Precise Real-Time Control

Imagine a balloon that, when inflating, sensed that it was about to burst and applied a patch automatically. While of little benefit for party balloons, such a system could greatly enhance the power output of a magnetically confined plasma. The energy liberated in fusion reactions increases strongly with the plasma pressure; therefore, maximizing the pressure is very beneficial. However, as the pressure increases, the magnetic bottle can "tear" and leak the pressure out, just like a party balloon. Researchers on the DIII-D tokamak have developed a system that automatically strengthens the magnetic bottle in the precise location at which it would tear, allowing pressures 20% higher. In a fusion power experiment such as the upcoming ITER, this could lead to approximately 40% higher energy production.

The real-time control system takes advantage of two special properties of the type of magnetic bottle known as a tokamak. First, the weak point at which the bottle will tear is a special place where the magnetic field lines have a unique structure. The location of this unique structure can be calculated from experimental measurements. To keep the bottle from tearing, a small amount of electrical current must be driven along the magnetic field at this precise location. This leads to the second special property, which is that electromagnetic waves (about 50 times higher frequency than those in a household microwave oven) can be aimed to a spot only an inch or two wide in the tokamak and drive current.

The explanation may sound simple, but the practical implementation required significant improvements in the real-time controls of DIII-D. The time for the plasma to tear, if not properly treated, is only a few thousandths of a second. The control system developed for DIII-D tokamak now has the capability to calculate the place where the plasma would tear and align the wave beam to this exact spot, adjusting the alignment more than one hundred times per second. The capability required for alignment was developed in experiments that allowed a tear to form, then patched it with the wave beam. Alignment to within about an inch of the tear was found to be required for efficiently repairing the tear. With this knowledge, high-speed computers can predict any changes in the required location as the experiment progresses. Applying this system before a tear occurred, the DIII-D tokamak was operated at pressures 20% higher than possible without real-time control. Technical details of this control system will be reported by D.A. Humphreys at the APS-DPP meeting in Denver, October 24-28, 2005.

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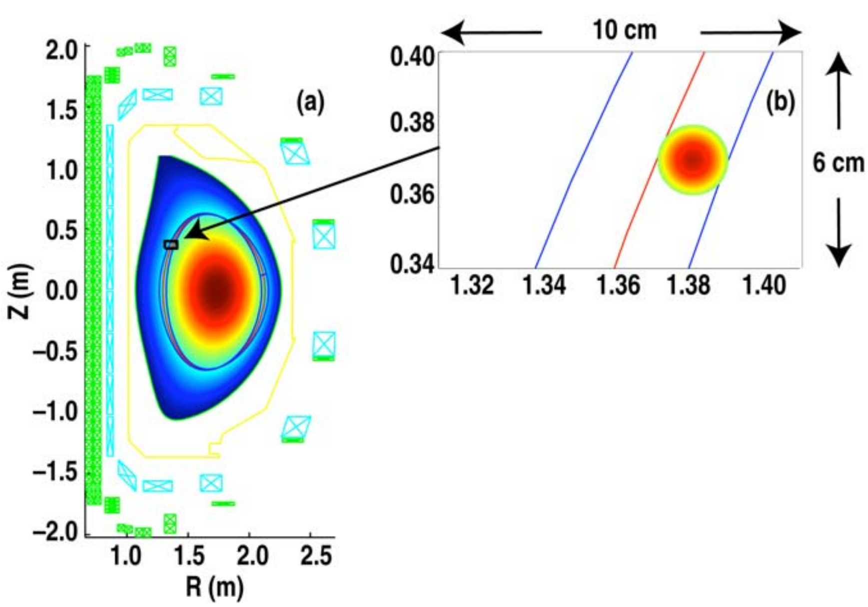

Figure 1. (a) Cross-section of the tokamak "magnetic bottle" showing the fusion plasma surrounded by magnet coils. The plasma is over 2 meters (about 7 feet) tall. (b) Expanded view showing the microwave beam (a round spot in this cross-section) aligned to within about half an inch of the center of the tearing region. The microwave beam is about 2.5 cm (1 inch) in diameter. These computer reconstructions are derived from experimental data.