Fusion instabilities lessened by unexpected effect

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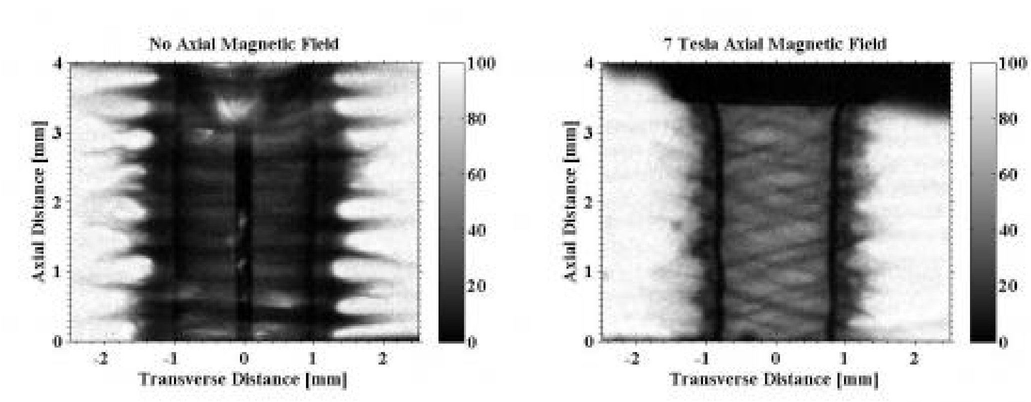

The image on the left demonstrates the instabilities that grow on the surface of a liner without a secondary magnetic field. This “bubble-and-spike” structure is caused by the magneto-Rayleigh Taylor instability, which commonly plagues z-pinch experiments. The bubble regions give up their mass to the spike regions; eventually, the bubbles break through the liner wall, and the liner’s ability to compress fuel is lost. By contrast, the image on the right shows the unique and unexpected helical instability structure that forms when the liner is premagnetized with a 7 Tesla field. Preliminary evidence suggests that this modified instability structure may work its way through the liner more slowly, enabling the liner to more effectively compress the fuel within. Credit: Tom Awe

(Phys.org) —A surprising effect created by a 19th century device called a Helmholz coil offers clues about how to achieve controlled nuclear fusion at Sandia National Laboratories' powerful Z machine.

A Helmholz coil produces a magnetic field when electrified. In recent experiments, two Helmholz coils, installed to provide a secondary magnetic field to Z's huge one, unexpectedly altered and slowed the growth of the magneto-Rayleigh-Taylor instabilities, an unavoidable, game-ending plasma distortion that usually spins quickly out of control and has sunk past efforts to achieve controlled fusion. "Our experiments dramatically altered the nature of the instability," said Sandia physicist Tom Awe. "We don't yet understand all the implications, but it's become a different beast, which is an exciting physics result."

The experiments were reported in December in *Physical Review Letters*.

The purpose of adding two Helmholz coils to fusion experiments at the Z machine, which produces a magnetic field 1,000 times stronger than the coils, was to demonstrate that the secondary field would create a magnetic barrier that, like insulation, would maintain the energy of charged particles in a Z-created plasma. Theoretically, the coils' field would do this by keeping particles away from the machine's walls. Contact would lower the fusion reaction's temperature and cause it to fail.

Researchers also feared that the Helmholz field might cause a short in Z's huge electrical pulse as it and its corresponding magnetic field sped toward the target, a small deuterium-stuffed cylinder.

Z's magnetic field is intended to crush the cylinder, called a liner, fusing the deuterium and releasing neutrons and other energies associated with nuclear fusion. Anything hindering that "pinch" or "z-pinch," would doom the experiment.

In preliminary experiments by Awe's group, the coils indeed buffered the particles and didn't interfere with the pinch.

Enter the coils

But unexpectedly, radiographs of the process showed that the coils' field had altered and slowed the growth of the magneto-Rayleigh-Taylor instabilities. Those distortions had been thought to occur unavoidably because even the most minute differences in materials turned to plasma are magnified by pressures applied over time.

The strength of instabilities seen in hundreds of previous z-pinches was reduced, possibly significantly.

The typical distortion pattern also changed shape from horizontal to helical.

The unexpected results occurred in a series of experiments to study a concept called Magnetized Liner Inertial Fusion, or MagLIF.

Experimental process like French toast

Researchers placed the Helmholz coils around a liner containing deuterium so the coils' magnetic field lines soaked both container and fuel over a period of milliseconds. The relatively slow process, like soaking bread in beaten eggs and milk to make French toast, allowed time for the magnetic field lines to fully permeate the material. Then the liner was crushed in tens of nanoseconds by the massive magnetic implosion generated by Sandia's Z machine. In previous attempts to use Z's huge field without the Helmholz coils, radiographs showed instabilities appearing on the exterior of the liner. These disturbances cause the liner's initially smooth exterior to resemble a stack of metallic washers, or small sausage links separated by horizontal rubber bands. Such instabilities increase dramatically in nanoseconds, eating through the liner wall like decay through a tooth. Eventually, they may collapse portions of the inner wall of the liner, releasing microrubble and causing uneven fuel compression that would make fusing significant amounts of deuterium impossible.

The disturbances are a warning sign that the liner might crumple before fully completing its fusion mission.

But firing with the secondary field running clearly altered and slowed formation of the instability as the liner quickly shrank to a fraction of its initial diameter. Introducing the secondary magnetic field seemed to realign the instabilities from simple circles—stacked washers, or rubber bands around sausages—into a helical pattern that more resembled the slanting patchwork of a plaid sweater.

Like a kayak crossing a river

Researchers speculate that the vertical magnetic field created by the helical coils, cutting across Z's horizontal field, may create the same effect as a river slanting a kayak downstream rather than straight across a channel. Or it may be that the kayak's original direction is pre-set by the secondary magnetic field to angle it downstream. Whatever the reason, the helical instability created does not appear to eat through the liner wall as rapidly as typical horizontal Rayleigh-Taylor instabilities.

Flashes of X-rays that were released when material from the horizontal instabilities collided in the liner's center no longer appeared, suggesting more uniform fuel compression occurred, possibly a result of the increasing resistance of the implanted vertical magnetic field to the compression generated by the Z horizontal field.

The overall approach of Awe and his colleagues uses a method described in two papers by Sandia theorist Steve Slutz. In a 2010 article in *Physics of Plasmas*, Slutz suggested that the magnetic field generated by Z could crush a metallic liner filled with deuterium, fusing the atoms. Slutz and co-authors then indicated, in a 2012 paper in *Physical Review Letters*, that a more powerful version of Z could create high-yield fusion—much more fusion energy out than the electrical energy put in.

The apparently simple method—turn on a huge magnetic field and wait a few nanoseconds—takes for granted the complicated host of engineered devices and technical services that allow Z to function. But, those aside, the process as described by Slutz needed only two additional aids: a powerful laser to preheat the fuel, making it easier for the compressed fuel to reach fusion temperatures, and Helmholz coils above and below the target to generate a separate, weaker magnetic field that would insulate charged particles from giving up their energy, thereby lowering the temperature of the reaction.

Ongoing experiments on Z will determine how well reality bears out Slutz's predictions. But for now, the reduction of distortions has been warmly received by fusion researchers, leading to an invitation to Awe to present his team's results at the 55th Annual Meeting of the APS Division of Plasma Physics, the world's largest plasma meeting.

The principle of the Z machine is simple: Z's magnetic force can crush any metal in its path. Possibly, then, it could force the fusion of ions like deuterium in a metal liner a few millimeters in diameter. The magnetic field would crush the liner's fuel to the diameter of a human hair, causing deuterium to fuse. This would release neutrons that could be used to study radiation effects, one of the key concerns of the National Nuclear Security Administration, which funds the bulk of this research. Further, in the far future, and with additional engineering problems solved, the technique when engineered to fire repetitively could be used as the basis for an electrical generating plant whose fuel is sea water, a carbon-free energy source for humankind.

"Of course the reality is not that simple," said Awe, "but the new ability to modify the instability growth on the liner surface may be a step in the right direction."

For more information, visit the Z machine website.

More information: T. J. Awe, R. D. McBride, C. A. Jennings, et al. "Observations of Modified Three-Dimensional Instability Structure for Imploding z-Pinch Liners that are Premagnetized with an Axial Field." *Phys. Rev. Lett.* 111, 235005 (2013)

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