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Cross-pollinating physicists use novel technique to improve the design of facilities that aim to harvest fusion energy

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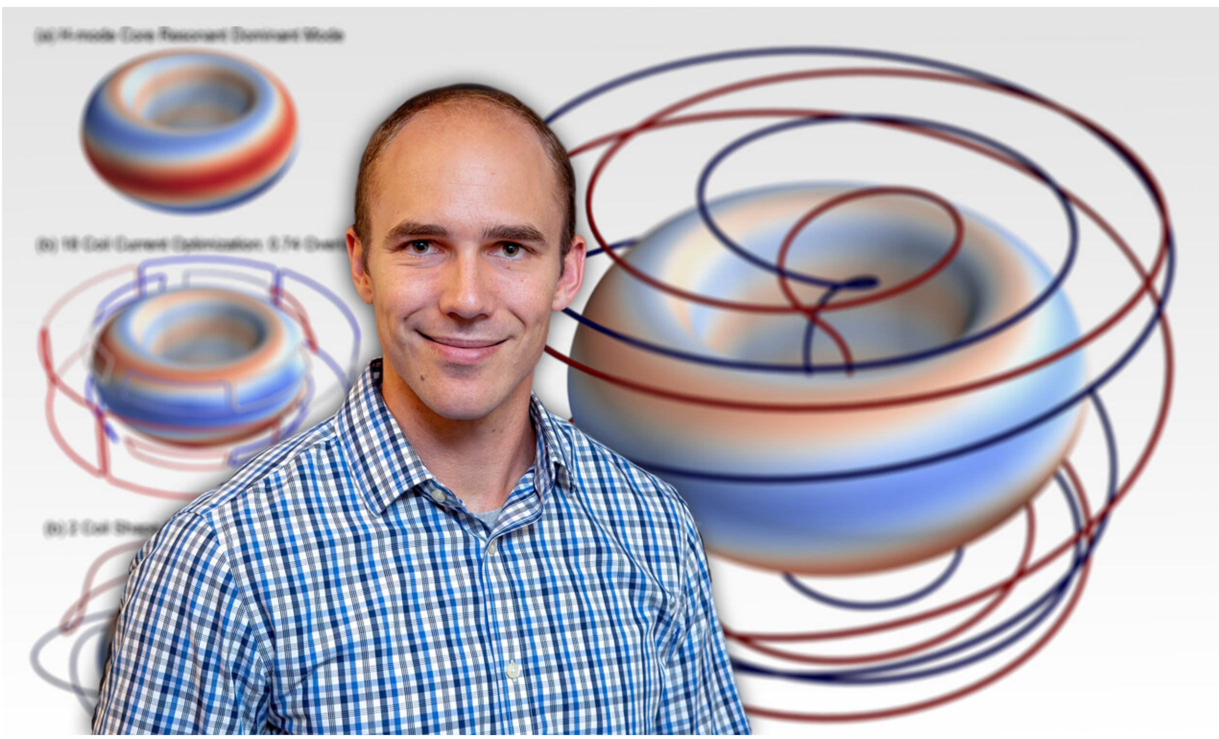

Physicist Nik Logan next to computer-generated images of fusion plasma. Credit: Elle Starkman / PPPL Office of Communications

Physicists are like bees—they can cross-pollinate, taking ideas from one area and using them to develop breakthroughs in other areas. Scientists at the U.S. Department of Energy's (DOE) Princeton Plasma Physics

Laboratory (PPPL) have transferred a technique from one realm of plasma physics to another to enable the more efficient design of powerful magnets for doughnut-shaped fusion facilities known as tokamaks. Such magnets confine and control plasma, the fourth state of matter that makes up 99 percent of the visible universe and fuels fusion reactions.

Designing these magnets is not simple, especially when they must be precisely shaped to create complex, three-dimensional magnetic fields to control plasma instabilities. So it is appropriate that the new technique comes from scientists who design stellarators, cruller-shaped fusion devices that require such carefully constructed magnets. In other words, the PPPL scientists are using a stellarator computer code to envision the shape and strength of twisted tokamak magnets that can stabilize tokamak plasmas and survive the extreme conditions expected in a fusion reactor.

This insight could ease the construction of tokamak fusion facilities that bring the power of the sun and stars to Earth. "In the past, it was a journey of discovery," said Nik Logan, a physicist at the DOE's Lawrence Livermore National Laboratory who led the research while at PPPL. "You had to build something, test it , and use the data to learn how to design the next experiment. Now we can use these new computational tools to design these magnets more easily, using principles gleaned from years of scientific research." The results have been reported in a paper published in *Nuclear Fusion*.

Fusion, the power that drives the sun and stars, combines light elements in the form of plasma—the hot, charged state of matter composed of free electrons and atomic nuclei—that generates massive amounts of energy. Scientists are seeking to replicate fusion on Earth for a virtually inexhaustible supply of power to generate electricity.

The findings could aid the construction of tokamaks by compensating for imprecision that occurs when a machine is translated from a theoretical design to a real-life object, or by applying precisely controlled 3D magnetic fields to suppress plasma instabilities. "The reality of building anything is that it isn't perfect," Logan said. "It has small irregularities. The magnets we are designing using this stellarator technique can both correct some of the irregularities that occur in the magnetic fields and control instabilities." Doing so helps the magnetic field stabilize the plasma so potentially damaging bursts of heat and particles do not occur.

Logan and colleagues also learned that these magnets could act on the plasma even when placed at a relatively large distance of up to several meters from the tokamak's walls. "That's good news because the closer the magnets are to the plasma, the more difficult it is to design them to meet the harsh conditions near fusion reactors," Logan said. "The more equipment we can place at a distance from the tokamak, the better."

The technique relies on FOCUS, a computer code created mainly by PPPL physicist Caoxiang Zhu, a stellarator optimization scientist, to design complicated magnets for stellarator facilities. "When I was first building FOCUS as a postdoctoral fellow at PPPL, Nik Logan stopped by my poster presentation at an American Physical Society conference," Zhu said. "Later we had a conversation and realized that there was an opportunity to apply the FOCUS code to tokamak projects."

The collaboration between different subfields is exciting. "I'm happy to see that my code can be extended to a broader range of experiments," Zhu noted. "I think this is a beautiful connection between the tokamak and stellarator worlds."

Though long the number-two fusion facility behind tokamaks, stellarators are now becoming more widely used because they tend to create stable plasmas. Tokamaks are currently the first choice for a fusion reactor design, but their plasmas can develop instabilities that could damage a reactor's internal components.

Presently, PPPL researchers are using this new technique to design and update magnets for several tokamaks around the world. The roster includes COMPASS-U, a tokamak operated by the Czech Academy of Sciences; and the Korea Superconducting Tokamak Advanced Research (KSTAR) facility.

"It's a very practical paper that has practical applications, and sure enough we have some takers," Logan said. "I think the results will be helpful for the future of tokamak design."

More information: N.C. Logan et al, Physics basis for design of 3D coils in tokamaks, *Nuclear Fusion* (2021). DOI: 10.1088/1741-4326/abff05

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