Physicists improve method for designing fusion experiments

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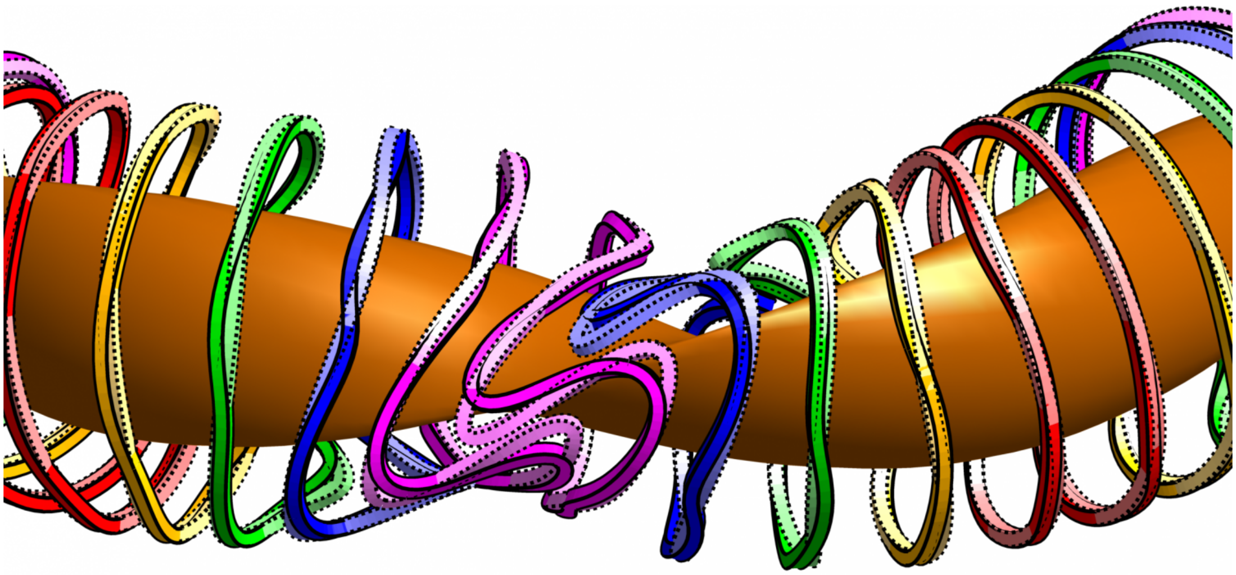

Fusion experiments known as stellarators work by confining a mass of superheated plasma (orange horizontal mass) inside a magnetic field generated by external electromagnetic coils (multicolored vertical bands). A UMD physicist has made a revision to the software tools used to design these complex coil shapes, allowing researchers to create better designs with more room between the coils for repairs and instrumentation. The solid lines denote shapes made by the old software, while the dotted lines denote shapes made by the new software. Credit: Matt Landreman

"Measure twice, cut once" is an old carpenter's proverb—a reminder that careful planning can save time and materials in the long run.

The concept also applies to the design of stellarators, which are complex nuclear fusion experiments meant to explore fusion's potential as an energy source. Stellarators work by confining a ring of blazing-hot plasma inside a precisely shaped magnetic field generated by external electromagnetic coils. When the plasma gets to several million degrees—as hot as the interior of the sun—atomic nuclei begin to fuse together, releasing massive amounts of energy.

Before turning a single bolt to build one of these rare and expensive devices, engineers create exacting plans using a series of algorithms. However, a wide variety of coil shapes can all generate the same magnetic field, adding levels of complexity to the design process. Until now, few researchers have studied how to choose the best among all potential coil shapes for a specific stellarator.

University of Maryland physicist Matt Landreman has made an important revision to one of the most common software tools used to design stellarators. The new method is better at balancing tradeoffs between the ideal magnetic field shape and potential coil shapes, resulting in designs with more space between the coils. This extra space allows better access for repairs and more places to install sensors. Landreman's new method is described in a paper published February 13, 2017 in the journal *Nuclear Fusion*.

"Instead of optimizing only the magnetic field shape, this new method considers the complexity of the coil shapes simultaneously. So there is a bit of a tradeoff," said Landreman, an assistant research scientist at the UMD Institute for Research in Electronics and Applied Physics (IREAP) and sole author of the research paper. "It's a bit like buying a car. You might want the cheapest car, but you also want the safest car. Both features can be at odds with each other, so you have to find a way to meet in the middle."

Researchers used the previous method, called the Neumann Solver for Fields Produced by External Coils (NESCOIL) and first described in 1987, to design many of the stellarators in operation today—including the Wendelstein 7-X (W7-X). The largest stellarator in existence, W7-X began operation in 2015 at the Max Planck Institute of Plasma Physics in Germany.

"Most designs, including W7-X, started with a specifically shaped magnetic field to confine the plasma well. Then the designers shaped the coils to create this magnetic field," Landreman explained. "But this method typically required a lot of trial-and-error with the coil design tools to avoid coils coming too close together, making them infeasible to build, or leaving too little space to access the plasma chamber for maintenance."

Landreman's new method, which he calls Regularized NESCOIL—or REGCOIL for short—gets around this by tackling the coil spacing issue of stellarator design in tandem with the shaping of the magnetic field itself. The result, Landreman said, is a fast, more robust process that yields better coil shapes on the first try.

Modeling tests performed by Landreman suggest that the designs produced by REGCOIL confine hot plasma in a desirable shape, while significantly increasing the minimum distances between coils.

"In mathematics, we'd call stellarator coil design an 'ill-posed problem,' meaning there are a lot of potential solutions. Finding the best solution is highly dependent on posing the problem in the right way," Landreman said. "REGCOIL does exactly that by simplifying coil shapes in a way that the problem can be solved very efficiently."

The development of nuclear fusion as a viable energy source remains far off into the future. But innovations such as Landreman's new method will help bring down the cost and time investments needed to build new stellarators for research and—eventually—practical, energy-generating applications.

"This field is still in the basic research stage, and every new design is totally unique," Landreman said. "With these incompatible features to balance, there will always be different points where you can decide to strike a compromise. The REGCOIL method allows engineers to examine and model many different points along this spectrum."

The research paper, "An improved current potential method for fast computation of stellarator coil shapes," Matt Landreman, was published February 13, 2017 in the journal *Nuclear Fusion*.

Provided by University of Maryland

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