



An international journal of news from the stellarator community

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Issue 189

December 2024
Phone: +1 (865) 482-5643

On the Web at <https://stelnews.info>

Researchers from CIEMAT's National Fusion Laboratory propose a novel concept for future stellarator reactors

Nuclear fusion research is at an exciting time. Initiatives proposing the design and construction of new experimental devices and reactor prototypes are flourishing at the international level and are succeeding in mobilizing public and private investment. In Spain, in particular, steps are being taken towards a National Strategy on Fusion. In this context, one of the research lines of the National Fusion Laboratory of CIEMAT is the design of magnetic fields that can form the basis of a stellarator-type fusion reactor.

In a stellarator, the electric currents passing through the coils create a magnetic field organized into nested magnetic surfaces in the shape of a deformed doughnut. This magnetic field confines a plasma composed of deuterium and tritium, as well as the charged alpha particles resulting from fusion. In order for the plasma to be hot enough and for fusion reactions to take place (and consequently in a future reactor to generate electricity), the magnetic field has to be designed extremely carefully. This is called optimizing the stellarator.

A fundamental objective of the optimization of the magnetic field of the stellarator is to ensure that the particles that make up the plasma remain along their trajectories, close to the same magnetic surface. This is a property known as “omnigenity.” When omnigenity is exactly achieved, the neoclassical transport (i.e., the transport associated with the magnetic geometry and particle collisions) of the device is comparable to that of

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a tokamak. However, to achieve omnigenity, it is necessary to globally (in the sense discussed more rigorously in the next paragraph) optimize each magnetic surface. This often results in coils that are very difficult to build. Recently, an alternative has been identified by researchers at the Theory Unit of the National Fusion Laboratory of CIEMAT. In their work, published in *Physical Review Letters* [1] (and briefly reviewed for a wider audience by *Physics Magazine* [2]), it is shown that it is possible to “split” each magnetic surface of the stellarator into several pieces and optimize each of them separately. The resulting stellarators have been called “piecewise omnigenous” (pwO).

Neoclassical stellarator optimization targets, either explicitly or implicitly, the second adiabatic invariant J . J is a property of the particle orbits in a magnetic field. In an omnigenous field, J is a constant of the magnetic surface, and the particles consequently remain on average tied to the magnetic surface along their orbits. However, making J constant imposes severe constraints on the topology of the magnetic field strength B [3]. In particular, the contours of constant B must close in the poloidal (θ), toroidal (ζ), or helical ($M\theta - N_p N \zeta$, with M and N integers and N_p the number of toroidal field periods) direction, as in the examples of Fig. 1. This can be difficult to combine with other design criteria of a stellarator reactor. Nevertheless, the vast majority of the

so-called second-generation stellarator devices are designed with a magnetic configuration that tries to approach omnigenity. This includes quasi-isodynamic and quasisymmetric configurations, two particular families of omnigenous configurations.

In Ref. [1], it is shown that omnigenity is a sufficient but not necessary condition to achieve tokamak-like neoclassical transport in a reactor-relevant collisionality regime. Instead of making J a magnetic surface constant, it is proposed to make it a piecewise constant. This removes some of the constraints imposed on B by omnigenity. A simple example of a pwO field is shown in Fig. 2. The numerical results presented in Ref. [1] show that approaching such a field, and thus optimizing with respect to piecewise omnigenity, results in good neoclassical transport properties. Moreover, it is shown that some magnetic configurations obtained in the past [4,5] (and, more recently, with state-of-the-art numerical tools [6]), solutions of the magnetohydrodynamic equations, are actually piecewise omnigenous. This explains their level of neoclassical transport, which is small even though they are far from full omnigenity.

This result radically broadens the space of accessible reactor-relevant configurations. Naturally, the next step is a rigorous assessment of other physics properties of nearly pwO configurations, in order to qualify them as

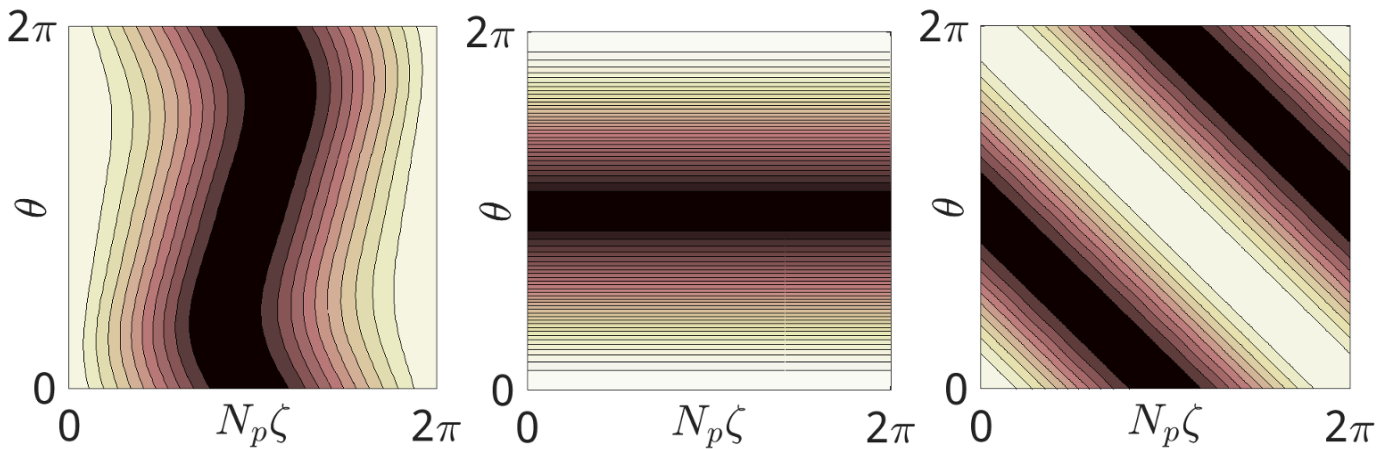


Fig. 1. B contours on the magnetic surface of a quasi-isodynamic (left), quasi-axisymmetric (center) and quasi-helically symmetric (right) field. θ and ζ are the poloidal and toroidal Boozer angles, respectively, and a darker color corresponds to a weaker field.

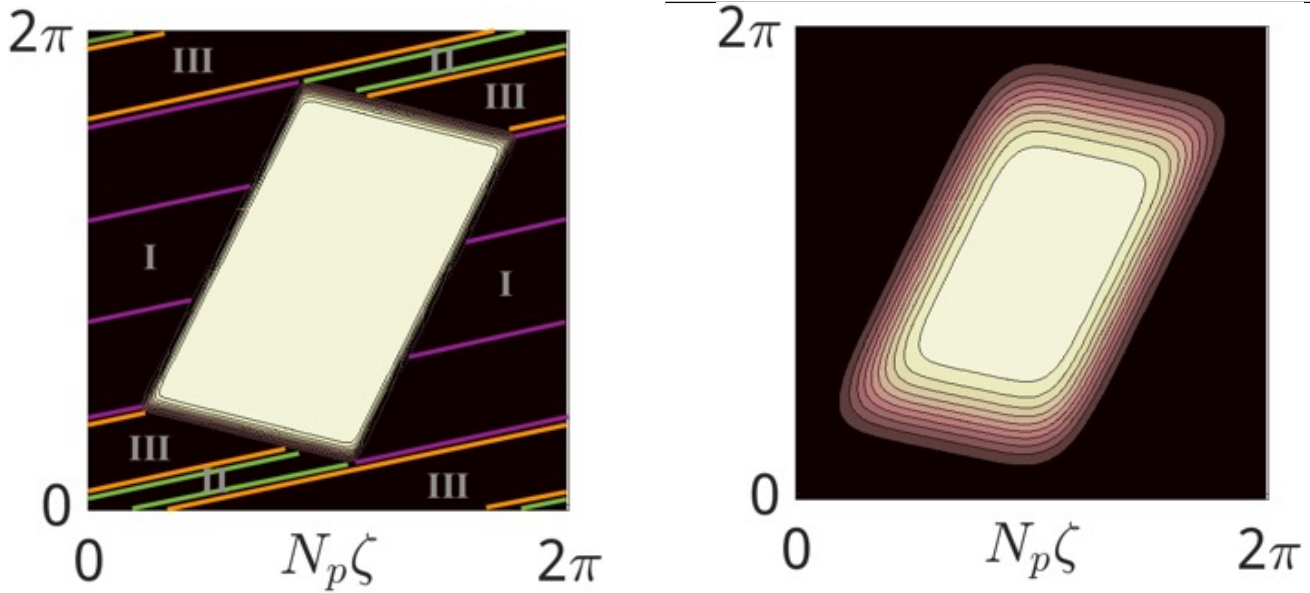


Fig. 2. B contours of an exactly (left) and nearly (right) pwO magnetic field. In the exactly pwO field, J is constant within the regions labelled by I, II, and III, and discontinuous at the boundaries between regions.

serious contenders for quasi-isodynamic or quasisymmetric configurations. The supplemental material of Ref. [1] indeed shows preliminary results indicating that piecewise omnigenity can in principle be compatible with good alpha particle confinement, low turbulent transport, and coil feasibility.

References

- [1] J. L. Velasco, I. Calvo, F. J. Escoto, et al. Phys. Rev. Lett. **133**, 185101 (2024).
- [2] R. Berkowitz, Physics 17, s124 (2024).
- [3] J. R. Cary and S. G. Shasharina, Phys. Rev. Lett. **78**, 674 (1997).
- [4] D. A. Spong, S. P. Hirshman, J. C. Whitson, et al., Phys. Plasmas **5**, 1752 (1998).
- [5] C. D. Beidler, K. Allmaier, M. Y. Isaev, et al., Nucl. Fusion **51**, 076001 (2011).
- [6] D. Bindel, M. Landreman, and M. Padidar, Plasma Phys. and Control. Fusion **65**, 065012 (2023).

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Posts of Interest

Internet posts that the Editor deems of interest:

- [Nuclear Fusion's New Idea: An Off-the-Shelf Stellarator](#)
- [Fusion's public-relations drive is obscuring the challenges that lie ahead](#)
- [PPPL's new tabletop stellarator uses off-the-shelf magnets](#)

Interview with Milena Roveda, CEO, Gauss Fusion

Research into fusion reactors has been conducted at universities and institutes for decades. Recently, private investors have also been making inroads into this field of research. What makes them so optimistic?

That's easy to explain. There are several factors that have led to changes in recent years. Until now, as you know, research into fusion has mainly been in the hands of institutes, such as the Max Planck Institute. But this technology cannot be industrialised by a research institute alone. You need industry - not just as a supplier, but as a builder.

I am often asked whether we are competing with ITER. I always reply: We are not competing because ITER is not an industrial project. ITER is supposed to do science, namely basic research. We, on the other hand, are commercialising what already exists.

But you are also building on the results of ITER.

On the results of ITER and on the results of Wendelstein, among others. Of course. It's not competition, we complement each other. But what we bring to the table that these institutions don't have is entrepreneurship. We really are entrepreneurs who drive the whole thing forward. We don't compete with the scientists, we collaborate with them and bring something new to the table. And it's this entrepreneurship that makes the difference.

There are more than 40 fusion companies worldwide. How does Gauss Fusion differ from them?

Like us, most of them are organised in the FIA, the Fusion Industry Association. But apart from us, all the others are spin-offs, i.e. spin-offs from universities or research institutes. We are the only start-up that was created by entrepreneurs, and I'm explicitly not saying by companies. There are large companies or groups that are excellent, but they are now mostly run by managers and not by entrepreneurs.

Who at Gauss Fusion epitomises this entrepreneurial spirit?

We have several entrepreneurial families on board. There is Frank Laukien, who runs Bruker, a company co-

founded by his father that manufactures scientific instruments. Bruker is regarded as the world market leader in magnetic resonance spectroscopy. Or the Malacalza family, a prominent Italian entrepreneurial family who, among other things, manufactured the magnets for ITER with the company ASG. Then there is the family of Pierre Prioux, the President of Alcen.

How has your career progressed so far?

I started my career at Bayer and worked there for ten years. After that, I was self-employed for more than 25 years. I feel more like an entrepreneur than an employee. That's a different attitude.

What does this mean for the power plant project?

This different mentality is important: if we have a problem, we can solve it if we really want to. We can make it work. That is one of the points where I am confident that we can finally break this 30-year vicious circle. Gauss Fusion is putting on its entrepreneurial hat and will manage the construction of the first industrially manufactured European fusion power plant.

Are there other drivers for the fusion power plant?

Among other things, there is the political situation in Europe, which has led to huge price increases, especially for electricity. In Italy, there are cafés that have been family-owned for decades and now have to close because they can no longer pay their electricity bills. I think this is also a wake-up call for all of us. We cannot continue to make ourselves dependent, we have to lead the way in the technology of future energy generation.

What strategy is Gauss Fusion pursuing to achieve this goal?

We take a pragmatic approach. Let me give you an example: there is a very glaring material problem, because there are no materials that can withstand neutron bombardment over a long period of time. We won't have them in 30 years' time either, so we are going to build our stellarator in a modular way so that the critical parts can be replaced quickly and a full year of downtime is not necessary. We'll come up with something for this, but that's not a question for the physicists, it's a question for the engineers.

Are there any topics on which you are also working on innovations yourself at Gauss Fusion?

Yes, there are three topics. Firstly, magnets, because we have this topic in-house with Bruker EAS and ASG. We want to work very innovatively in this area. The second area is tritium and the fuel cycle, and the third is plasma heating. The latter is currently being done with gyrotrons — these are microwave oscillators — whereby 150 to 180 units are needed for a tokamak, the efficiency of which has a significant impact on the overall energy balance.

What opportunities does the European industry have?

Very good. We have the longer and better basic research and the better industry. The largest fusion company at the moment is Commonwealth Fusion in the USA, which has received two billion US dollars in capital. But they come to us in Germany and buy parts from our industry. We have a good chance of becoming a leader in Europe again. We could actually have this industrial renaissance in Europe with fusion, which means prosperity and jobs for our continent. But we must finally do something. At the moment, we talk too much and do too little. Importantly, leading European companies have recently come together to form the European Fusion Association (EFA). The aim is to accelerate the European industrialisation of fusion energy.

It's not just the USA that is in tough competition with us in terms of time, but above all China. How far along are the Chinese?

The Chinese fusion industry has the advantage that it is massively subsidised by the Chinese government, as China wants to become the number one in this future technology, driven primarily by politics. All countries involved in ITER are still working together, including China, Russia, Korea and India. However, there is fierce competition for industrial fusion power plant projects. And China is already building the first prototypes.

At Gauss Fusion, you have probably drawn up a plan for how you can build a functioning power plant by the mid-2040s. What does it look like?

We are still in the planning stage. We have divided these 20 years into three phases. The first phase is “conceptual design,” in which we actually put our concept on paper. We are currently in this phase and will be finished by next year. Then comes the “engineering” phase, in which we start to build the first prototypes. That will take

around 6–8 years. The third phase is the actual construction phase, which will take 8–12 years. It won't be a purely German project, because I personally don't believe that any country, not even the USA, which is big and rich, could do it alone. But Europe can do it, not with all 27 countries, but only with a handful. If they join forces, then we can do it. That is our strategy.

What role do the prototypes play? Do you build them to test certain critical functions?

Yes, for example the assembly of the magnets. We will investigate very carefully to what extent these magnets can be taken apart and reassembled.

Isn't that extremely difficult with the Stellarator because the coils are so strangely wound?

Yes, the non-planar coils are a bit strange, but we have the person responsible for the magnets at ITER with us, a man with 40 years of professional experience. He is confident that it will work. And we want to avoid the typical German “over engineering.”

Do we even need all that energy from nuclear fusion and why?

For example, there is a study by the International Energy Agency. It conservatively estimates the increase in electricity demand in Europe at 25% by 2050. The more aggressive estimate is 70%. The demand will be generated by electromobility in passenger transport, among other things, but also in heavy goods transport. For modes of transport that are not so easy to convert to battery operation, such as aircraft and ships, hydrogen and e-fuels must be produced using electrical energy, which is currently only possible with poor efficiency. Not forgetting the ongoing digitalisation, which requires large data centres, especially when AI algorithms are used. There are also studies that say that fusion is not primarily needed for electrical energy, but rather as process heat for industry and for the production of green hydrogen and e-fuels.

Submitted by Gauss Fusion
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