Piecewise omnigenous fields: a radically new family of optimized magnetic fields for stellarator reactors

J. L. Velasco, I. Calvo, E. Sánchez, F. J. Escoto, H. Thienpondt, F. I. Parra*

Laboratorio Nacional de Fusión, CIEMAT, 28040 Madrid, Spain

** Princeton Plasma Physics Laboratory, Princeton, NJ 08540, USA*

In stellarators, fusion plasmas are confined by means of a magnetic field organized into three-dimensional nested magnetic surfaces that is created by external coils. This makes stellarators qualitatively different to tokamaks, in which an inductive current is partially responsible for the magnetic field (which makes them prone to magnetohydrodynamic instabilities). However, the magnetic field of a stellarator has to be designed very carefully in order to have confinement properties similar to those of a tokamak. This is called optimizing the stellarator. In particular, in any candidate for a stellarator fusion reactor, the magnetic configuration is optimized to be close to omnigenity. In omnigenous stellarator magnetic fields [1], charged particles are perfectly confined in the absence of collisions and turbulence, as in an axisymmetric tokamak. When omnigenity is exactly achieved, the neoclassical transport (i.e., the transport associated to the magnetic geometry and particle collisions) of the device is comparable to that of a tokamak. Recently, thanks to theoretical and computational breakthroughs, stellarator configurations with unprecedented level of omnigenity have been achieved [2].

However, omnigenity imposes stringent constraints on the spatial variation of the magnetic field strength B [1]. In particular, the contours of constant B on the flux-surface must close either toroidally, poloidally or helically (figure 1). In a stellarator, these constraints sometimes lead to complicated plasma coils [3].

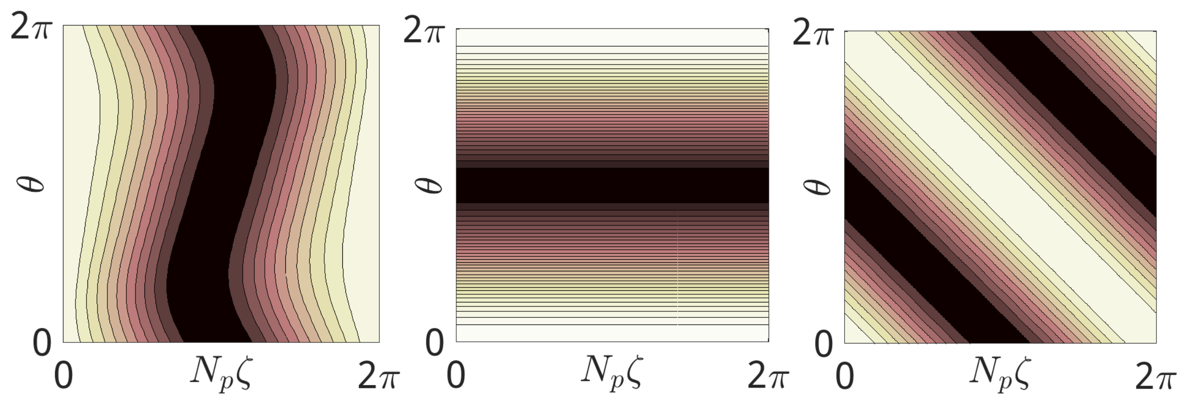

Figure 1: B-contours on the magnetic surface of a quasi-isodynamic (left), quasi-axisymmetric (center) and quasi-helically symmetric (right) field. θ and ζ are the poloidal and toroidal Boozer angles, respectively, N_p the number of field periods, and a darker color corresponds to a weaker field.

In this talk, a new notion of optimized magnetic fields, named *piecewise omnigenous stellarators* [4], will be presented. We will revisit the physical picture behind standard omnigenity, and then we will prove that piecewise omnigenous fields can also give exceedingly small collisional transport without satisfying the aforementioned topological constraints. In particular, the fact that the contours of constant B on the flux-surface do not close toroidally, poloidally or helically leads to the existence of several types of trapped-particle orbits (figure 2), which in turn gives rise to specific transport properties that are potentially relevant for a reactor.

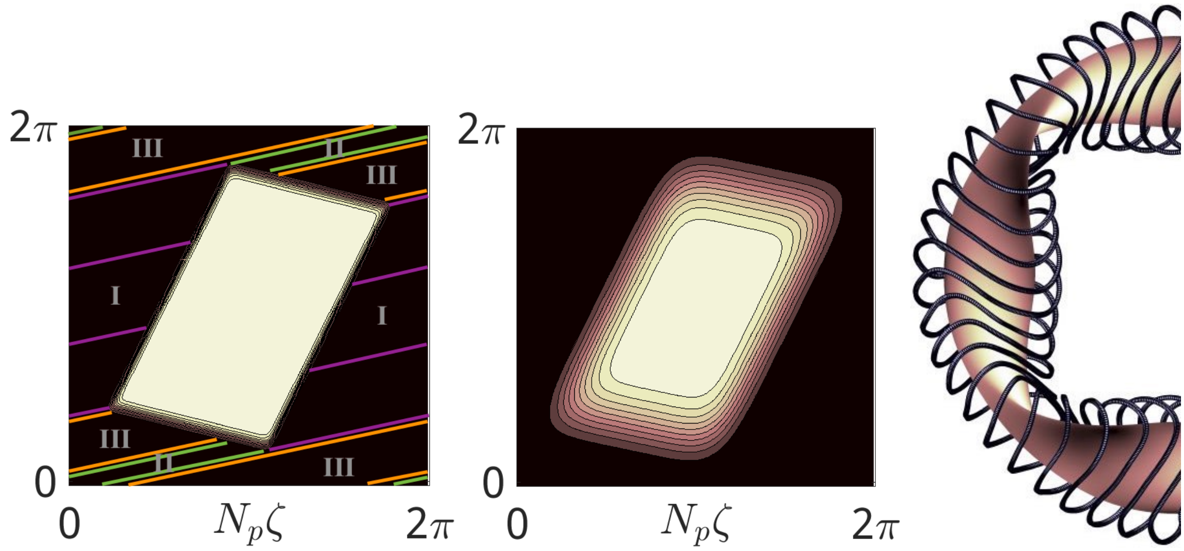

Figure 2: B-contours of an exactly (left) and a nearly (center) piecewise omnigenous magnetic field; lines of different colors represent different types of orbits. Example of nearly piecewise omnigenous stellarator configuration and coils (right) [4,6].

Piecewise omnigenous fields radically broaden the space of accessible reactor-relevant magnetic configurations [5]. We will show that, besides small collisional transport of the bulk plasma, these configurations may exhibit favourable properties regarding alpha-particle confinement, bootstrap current, impurity control, turbulent transport or coil simplicity (figure 2 right).

References

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