Optimal Shape of Stellarators for Magnetic Confinement Fusion

Yannick PRIVAT, IRMA, Université de Strasbourg - Strasbourg
Rémi ROBIN, Laboratoire Jacques-Louis Lions, Sorbonne Université - Paris
Mario SIGALOTTI, Inria Paris - Paris

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Nuclear fusion is a nuclear reaction involving the use of light nuclei. In order to use nuclear fusion to produce energy, high temperature plasmas must be produced and confined. This is the objective of devices called tokamaks, steel magnetic confinement chambers having the shape of a toroidal solenoid. The magnetic field lines in tokamaks form helicoidal loops, whose twisting allow the particles in the plasma to be confined. Indeed, twisting allows to counter the vertical drift that would otherwise affect particles, in opposite directions for ions and for electrons.

Unfortunately, the twisting of magnetic field requires a current to be induced within the plasma, inducing intermittency, instabilities, and other technological challenges. A possible alternative solution to correct the problems of drift of magnetically confined plasma particles in a torus is to modify the toroidal shape of the device, yielding to the concept of stellarator. This system has the advantage of not requiring plasma current and therefore of being able to operate continuously ; but it comes at the cost of more delicate coils (non-planar coils) and of a more important transport.

Despite the promise of very stable steady-state fusion plasmas, stellarator technology also presents significant challenges related to the complex arrangement of magnetic field coils. These magnetic field coils are particularly expensive and especially difficult to design and fabricate due to the complexity of their spatial arrangement.

In this talk based on [1], we are interested in the search for the optimal shape of stellarators, i.e., the best coil arrangement (provided that it exists) to confine the plasma. Let us assume that a target magnetic field B_T is known. It is then convenient to define a coil winding surface (CWS) on which the coils will be located. The optimal arrangement of stellarator coils corresponds then to the determination of a surface (the CWS) chosen to guarantee that the magnetic field created by the coils is as close as possible to the target magnetic field B_T. Of course, it is necessary to consider feasibility and manufacturability constraints. We will propose and study several relevant choices of such constraints.

In this talk we will analyze the resulting problem as follows : first we will establish the existence of an optimal shape, using the so-called reach condition ; then we will show the shape differentiability of the criterion and provide the expression of the differential in a workable form ; finally, we will propose a numerical method and perform simulations of optimal stellarator shapes. We will also discuss the efficiency of our approach with respect to the literature in this area.

[1] Y. Privat, R. Robin, M. Sigalotti. *Optimal shape of stellarators for magnetic confinement fusion*, 2021. Preprint.

Contact : `remi.robin@sorbonne-universite.fr`