Stellarators with Permanent Magnets

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Stellarators, tokamaks and other devices for fusion plasma confinement use electromagnets to create the magnetic field. In the case of stellarators, the required magnetic-field coils can be very complicated and contribute significantly to the overall cost of the device. It has recently been suggested that permanent magnets could be used to shape the plasma and drastically simplify the coils [1]. This talk will discuss mathematical aspects of this idea, in particular the problem of how to arrange the magnets.

Permanent magnets cannot create toroidal magnetic flux but they *can* create poloidal flux and thus twist magnetic field lines. Toroidal-field coils are therefore unavoidable, but much (or all) of the plasma shaping could be accomplished by permanent magnets. In contrast to coils, they can easily be arranged in complicated patterns and do not require power supplies or cooling, but suffer from other disadvantages, such as limitations in field strength, non-tunability, and the possibility of demagnetization.

The central mathematical question is how to arrange permanent magnets to produce a desired magnetic field inside the plasma. It will be shown that this problem is no more difficult – in fact, it is in a certain sense easier – than that of finding suitable coils in ordinary stellarator design. Moreover, there is great freedom in choosing the magnetisation $\mathbf{M}(\mathbf{r})$ in the region occupied by the magnets since the magnetic field they produce is invariant under the gauge transformation $\mathbf{M} \to \mathbf{M} + \nabla\chi$, where $\chi(\mathbf{r})$ is any function that vanishes on the boundary of the region. This freedom can be used to minimise the maximum value of $|\mathbf{M}(\mathbf{r})|$, which is limited to about 1.4 T/μ_0 for commercially available magnets.

Several concrete examples of stellarator fields with permanent magnets will be shown and discussed in the talk, including a quasi-axisymmetric stellarator using only 8 identical, circular coils.

[1] P. Helander, M. Drevlak, M. Zarnstorff and S.C. Cowley, accepted for publication in Phys. Rev. Lett. (2020).