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Design of a permanent magnet stellarator

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Stellarators have attractive properties, like low recirculating power, steady-state operation and free of disruptions, but they also suffer the engineering complexities, especially complicated non-planar coils. Recently, permanent magnet has been proposed to produce the three-dimensional component of stellarator magnetic fields and simplify the required electromagnetic coils [1, 2]. Here, we are going to introduce new methods to optimize permanent magnets for advanced stellarators and the design of a permanent magnet quasi-axisymmetric (QA) stellarator.

Like the coil design problem, the design of permanent magnets comes after the optimization of the configuration. The QA configuration, NCSX, which was partly built but unfortunately cancelled due to cost overrun, is used as the target equilibrium. TF coils and the vacuum vessel are also re-used. The volume-average magnetic field is scaled down to 0.5 T which is the maximum allowable field produced by the TF coils. Some key parameters of the equilibrium are $N_{fp} = 3, R_0 = 1.44\text{ m}, a = 0.32\text{ m}, V_{plasma} = 2.96\text{ m}^3, <\beta>= 4.1\%$. All the external 3-D field will be produced by permanent magnets.

This first method is inspired by the idea that surface current potential is the perpendicular magnetic dipole moment per unit area. A linear method is proposed to design perpendicular permanent magnets subjected to material constraints [2]. However, the linear method cannot explicitly incorporate the reserved windows on the vacuum vessel and the magnet layouts are not fully optimized. A new code, FAMUS [3], has been developed using the topology optimization techniques. FAMUS uses the density method to determine the presence of permanent magnet in pre-described meshes. A penalization coefficient is applied to polarize the distribution of the normalized density. A perpendicular-only design is shown in Fig. 1. Most the magnets are located on the inboard side of the machine and this provides vast outboard access, which will be extremely attractive for future fusion devices.

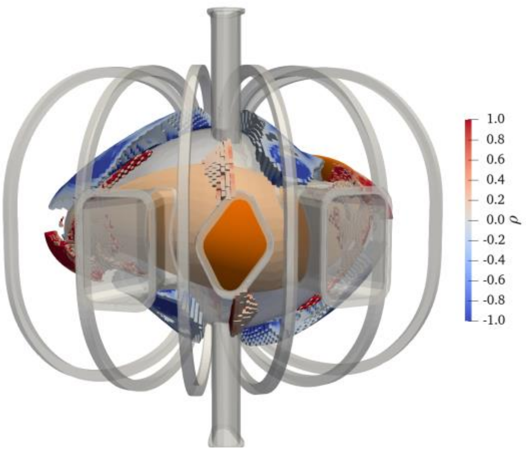

Fig. 1. Outboard view of the perpendicular permanent magnets together with TF coils for the half-Tesla NCSX configuration.

Other designs can also be obtained by using FAMUS. The orientation of the magnets can be relaxed to improve the magnetic efficiency and form the "Halbach" array. A design aiming at reducing the complexity of construction [4] is shown in Fig. 2(a). The magnets are in curved-bricks and the orientations are freely varied. The magnets will be mounted on planar ribs, as shown in Fig. 2(b). Free-boundary reconstructions using permanent magnets and planar TF coils have been performed. All the designs are proven to have good accuracy in supporting the target equilibrium.

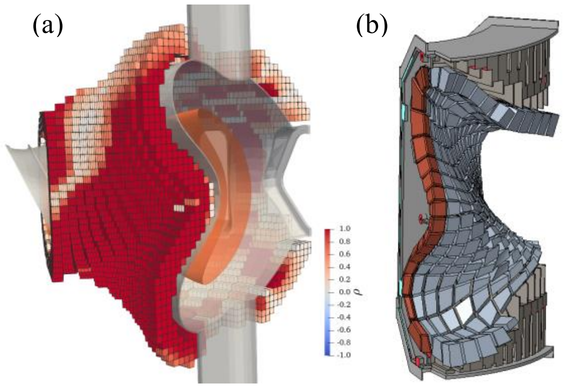

Fig. 2. (a) The distribution of the normalized density for the curved bricks case. (b) CAD image of a subset of magnets attached to planar mounting structures.

The results show that permanent magnet has great potential in significantly reducing the coil complexity and providing large access on the outboard side. PPPL is going to build one sixth of the magnets for the half-Tesla quasi-axisymmetric stellarator, funded by ARPA-E.

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References

[1] P. Helander *et al.,* Phys. Rev. Lett. **124**, 095001 (2020)
[2] C. Zhu *et al.,* Nucl. Fusion, **60**, 076016 (2020)
[3] C. Zhu *et al.,* Nucl. Fusion, accepted (2020)
[4] K. Hammond *et al.,* Nucl. Fusion, accepted (2020)