Next-generation stellarators in the era of HTS: opportunities and limitations in the path to fusion reactors.

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In the last years, high-temperature superconductors (HTS) have been put forward as a possible route to accelerate the demonstration of magnetic confinement fusion for energy production. The access to stronger magnetic fields could, in principle, allow to reduce the physical size of the fusion reactor and, potentially, lower its capital cost. Parallel to this development, the Wendelstein 7-X optimised stellarator reached some of its project goals already in the first experimental campaigns, demonstrating the constructability of its low-temperature superconducting magnets [1], the effectiveness of the neoclassical and magnetohydrodynamic optimisation in so-called quasi-isodynamic (QI) configurations [2] and stable detachment with an island divertor [3].

In this talk, we discuss the potential impact of the development of HTS-based 3D coils in the physics and engineering design of fusion reactors based on second-generation optimised QI configurations [4, 5]. We highlight critical issues, necessary developments and new niches for experimental, theoretical and computational research that are brought about by the access to stronger magnetic fields. Moreover, we explain how the present stellarator knowledge basis nuances and constrains the high-field approach to fusion when applied to 3D magnetic configurations, both from a physics scenario and reactor technologies perspectives.

In light of this discussion, we draw consequences for the design and scope of next-step stellarator devices. Two distinct pathways are discussed: (1) a proof-of-principles medium-size device that demonstrates the second-generation optimised stellarators, with reduced turbulent transport and excellent fast ion confinement properties [5], and (2) a high-field device able to showcase fusion energy gain. The former is proposed to be designed under dynamic-similarity principles with respect to a specific reactor design point that is consistent with the known physics basis and is compatible with basic fusion reactor technologies. Pathway (1), we argue, would have higher value for informing subsequent decisions on a pilot stellarator fusion plant.

[1] T.S. Pedersen et al. 2016 Nature Communications 7, 13493.
[2] A. Dinklage et al. 2018 Nature Physics 14, 855. C. D. Beidler et al. 2021 Nature 596, 221.
[3] O. Schmitz et al. 2020 Nuclear Fusion 61, 016026.
[4] J. A. Alonso et al 2022 Nuclear Fusion 62, 036024.
[5] E. Sánchez et al 2023 Nuclear Fusion 63, 066037.