A quasi-isodynamic configuration with good confinement of fast ions at low β

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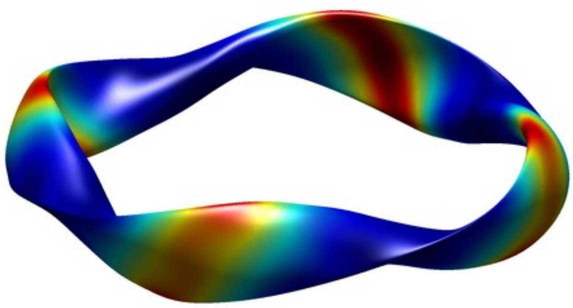
The stellarator possesses some advantages with respect to the tokamak as a fusion reactor concept. Most of the current is externally generated, which reduces the hazard of disruptive current instabilities. Furthermore, the absence of inductive current allows a more straightforward steady-state operation than in tokamaks. However, the lack of axisymmetry of the stellarator implies that good confinement is not guaranteed but requires careful tailoring of the magnetic configuration. The present generation of optimized stellarators, such as HSX and W7-X, are based on magnetic configurations optimized for good neoclassical confinement of thermal species. The optimization of HSX is based on the concept of quasi-symmetry [1], whereas the optimization of W7-X relies on the notion of quasi-isodynamicity [2]. The neoclassical optimization was first demonstrated experimentally in HSX [3], and more recently, in W7-X [4]. However, HSX and W7-X do not confine fast ions (FI) sufficiently well, and further optimization is required. Recently, new vacuum quasi-symmetric configurations optimized for FI confinement have been obtained [5, 6]. In contrast, in quasi-isodynamic devices, FI confinement is known to improve with plasma pressure (β) [7] and so far has been shown to be good enough only in high-β scenarios [8].

This work presents a new four-period stellarator configuration with aspect ratio A=10 and a quasi-isodynamic magnetic field with B=5 T at the magnetic axis. Its most salient property is an excellent confinement of fast ions for moderate values of $\langle\beta\rangle$ (~1.5%), which improves further for reactor-scale plasmas with $\langle\beta\rangle$~4%. The new configuration has been obtained using the optimization suite of codes STELLOPT [9], in which the code KNOSOS [10] has recently been included and is used to compute orbit-averaged quantities that are utilized as proxies for the confinement of energetic particles [11]. Monte Carlo full-orbit calculations with ASCOT [12] confirmed the good confinement of energetic ions predicted by the proxies computed with KNOSOS. In this configuration, the effective ripple is smaller than 0.5% in the plasma core and the Mercier MHD stability in all the plasma volume is supported by a significant magnetic well. The ballooning stability up to $\langle\beta\rangle$=4% has been demonstrated using the code COBRA [13]. A preliminary evaluation allows us to foresee a small bootstrap current for $\langle\beta\rangle$ values up to 4%. The inclusion of turbulent transport as an additional optimization criterion will be also discussed.



Magnetic field strength on the last closed flux surface of the quasi-isodynamic configuration at β=1.5%.

[1] J Nührenberg. Phys. Lett. A 129 (2) (1988).
[2] L. S. Hall et al. Phys. Fluids 18 (1995). P. Helander et al. Plasma Phys. Control. Fusion **51** (2009).
[3] J. M Canik. Phys. Rev. Lett. 98, 085002 (2007).
[4] C. Beidler et al. (2021) Nature **598**, E5 (2021).
[5] A. Bader et al. J. Plasma Phys. 86 (2020).
[6] S. Henneberg et al. Nucl. Fusion 59 (2) (2019).
[7] W. Lotz et al. Plasma Phys. Control. Fusion 34 (6) (1992).
[8] A. A. Subbotin, et al. Nucl. Fusion 46 (2006).
[9] S. A. Lazerson et al. (www.osti.gov/biblio/1617636-7pt).
[10] J. L. Velasco et al. J. of Comp. Phys. 418 (2020).
[11] J. L. Velasco et al. Nucl. Fusion 61 (11) (2021).
[12] E. Hirvijoki et al. Comput. Phys. Commun. 185 (2014).
[13] R. Sánchez et al. J. of Comp. Physics 161 (2) (2000).