Prospects of a Compact Large-Aspect Ratio Stellarator for Fusion Energy Production

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Significant progress has recently been made in the development of high temperature, rare earth superconductors, which may permit the operation of cost-efficient and compact high-field fusion power plants. While the application of this development is primarily being explored for tokamaks [1], it also offers new avenues for stellarators. Here, we present a 0.5D study of a compact, large-aspect ratio D-T stellarator reactor considering the geometry of the Helically Symmetric eXperiment (HSX) [2]. By scaling up the coils of HSX and defining the last closed flux surface at one half of the original minor radius, a viable fusion reactor concept with an aspect ratio of 20 has been obtained. Considering a scaling factor of eight, the HSX coil geometry yields a minor radius of 0.5 m, a major radius of 10 m and provides enough space for a 1.2 m thick combination of breeding blanket and neutron shield. Moreover, the ratio of the on-axis magnetic field to the maximum field at the coils of HSX is about a factor two. This would allow 10 T operation, considering a maximum field strength at the coils of about 20 T.

The ISS04 scaling [3] has been applied to study the performance of such a fusion reactor considering the alpha particle heating power, helium dilution, differences in the ion and electron temperatures, as well as impurity line radiation and Bremsstrahlung. By imposing that the line-average plasma density must be below the Sudo density limit [4] for 100 MW of heating power (5×10^{20} /m3) and assuming an ISS04 scaling factor of 2.35, a burning plasma with 700 MW of fusion power is predicted. The corresponding beta value is 3.5% and the neutron wall load is 2 MW/m^2, which is compatible with available first wall materials and blanket technology [5]. Thanks to the envisioned high-density operation, the concept features short fast-helium slowing down times (~0.2 s) and operation close to the plateau regime. This provides a small fast-particle beta (0.3%) and alleviates possible problems with neoclassical transport or overly strong bootstrap currents. With these very promising aspects, a compact large-aspect ratio fusion power plant seems to be feasible – assuming that an ISS04 scaling factor of 2.35 can be achieved by turbulence-optimized 3D magnetic fields.

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