Stellarator

Yevgeniy Gorenkov, Mariana Stryzhnova
National University of Food Technologies

Introduction. A stellaratoris is a device used to confine hot plasma with magnetic fields in order to sustain a controlled nuclear fusion reaction. It is one of the earliest controlled fusion devices, first invented by Lyman Spitzer in 1950 and built the next year at what later became the Princeton Plasma Physics Laboratory. The name refers to the possibility of harnessing the power source of the sun, a stellar object.

Stellarators were popular in the 1950s and 60s, but the much better results from tokamak designs led to them falling from favor in the 1970s. More recently, in the 1990s, problems with the tokamak concept have led to renewed interest in the stellarator design,[1] and a number of new devices have been built. Some important modern stellarator experiments are Wendelstein 7-X in Germany, the Helically Symmetric Experiment(HSX) in the USA, and the Large Helical Device in Japan.

Spitzer's innovation was a change in geometry. He suggested extending the torus with straight sections to form a racetrack shape, and then twisting one end by 180 degrees to produce a figure-8 shaped device. When a particle is on the outside of the center on one of the curved sections, by the time it flows through the straight area and into the other curved section it is now on the inside of the center. This means that the upward drift on one side is counteracted by the downward drift on the other.

To allow the tubes to cross without hitting, the torus sections on either end were rotated slightly, so the ends were not aligned with each other. This arrangement was less than perfect, as a particle on the inner portion at one end would not end up at the outer portion at the other, but at some other point rotated from the perfect location due to the tilt of the two ends. As a result, the stellarator is not "perfect" in terms of canceling out the drift, but the net result is to so greatly reduce drift that long confinement times appeared possible.

Comparison to tokamaks

The tokamak provides the required twist to the magnetic field lines not by manipulating the field with external currents, but by driving a current through the plasma itself. The field lines around the plasma current combine with the toroidal field to produce helical field lines, which wrap around the torus in both directions.

Although they also have a toroidal magnetic field topology, stellarators are distinct from tokamaks in that they are not azimuthally symmetric. They have instead a discrete rotational symmetry, often fivefold, like a regular pentagon.

It is generally argued that the development of stellarators is less advanced than tokamaks, although the intrinsic stability they provide has been sufficient for active development of this concept.

The three-dimensional nature of the field, the plasma, and the vessel make it much more difficult to do either theoretical or experimental diagnostics with stellarators. It is much harder to design a divertor (the section of the wall that receives the exhaust power from the plasma) in a stellarator, the out-of-plane magnetic coils (common in many modern stellarators and possibly all future ones) are much harder to manufacture than the simple, planar coils which suffice for a tokamak, and the utilization of the magnetic field volume and strength is generally poorer than in tokamaks.

However, stellarators, unlike tokamaks, do not require a toroidal current, so that the expense and complexity of current drive and/or the loss of availability and periodic stresses of pulsed operation can be avoided, and there is no risk of toroidal current disruptions. It might be possible to use these additional degrees of design freedom to optimize a stellarator in ways that are not possible with tokamaks.

References

1) M. Wakatani. *Stellarator and heliotron devices*. Oxford University Press, 1998.
2) Harris, J. H.; J. L. Cantrell, T. C. Hender, B. A. Carreras, and R. N. Morris (1985). "A flexible heliac configuration". *Nuc. Fusion* **25** (5): 623.
3) Canik, J. M.; et al. (23 February 2007). "Experimental Demonstration of Improved Neoclassical Transport with Quasihelical Symmetry". *Physical Review Letters* **98** (8): 085002.