Recent results from Wendelstein 7-X *En route* to a HELIAS reactor

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Abstract

Stellarators are toroidal magnetic confinement fusion devices undergoing a conceptual renaissance attracting interest as an alternative line to magnetic confinement fusion. Wendelstein 7-X (W7-X) is an optimized stellarator built to assess the capabilities of the HELIAS (HElical Axis Advanced Stellarator) line as a potential fusion reactor. Differently to tokamaks, already the vacuum field made from helical and toroidal field components generates a rotational transform as required to confine a hot plasma. Since no large plasma currents need to be induced, the free energy in stellarators is much less than in tokamaks. Stellarators are not affected by current quenches and runaway electrons. And stellarators do not show density limits allowing reactor operation at lower fast-particle pressure. All in all, stellarators enjoy quiescent stable plasma operation without large current drive requirements - a positive aspect for reactor economy. But there are reasons why stellarator research was left a small niche over years: in hot plasmas at almost collision-less (long-mean-free-path (lmfp)) conditions, localized trapped particles are expected to hinder the confinement of not only the hot plasma but also fusion-born α particles. Overcoming resulting drawbacks, stellarator fields have substantial flexibility in shaping: stellarator optimization is a concept to pre-compute and designing magnetic fields according to physics criteria. As a proof-of-concept device, W7-X is equipped with superconducting coils that allow quasi steady-state plasma operation. The scientific mission of W7-X (operated since 2015) is linked to crucial aspects for stellarator reactor operation. A complete demonstration of operation at high plasma pressure in the lmfp regime will require heating upgrades, advanced fueling capabilities and reactor grade plasma facing components. At present, W7-X is upgraded with water-cooled wall elements and heating power. First experiments on W7-X, however, have been conducted with an uncooled divertor and lower heating power. Favorable divertor operation will be reported in a separate presentation in this meeting. In this paper, aspects relevant to integrated operation will be reported: the reduction and full control of residual toroidal plasma currents (fully in line with neoclassical theory), the reduction of Pfirsch-Schlüter currents resulting in a robust magnetic field in the presence of a hot plasma and good confinement of the thermal plasma with appropriate fueling. Limits in confinement due to anomalous transport indicate the potential role of 3D turbulence. Differently to expectations, dangerous impurity accumulation was not observed. Fast ions generated by neutral beam injection were found to follow orbit calculations. All findings will be discussed in view of the forthcoming operation campaign after the commissioning of water-cooled plasma facing components.