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Divertor concept development for the W7-X stellarator experiment

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The Wendelstein 7-X (W7-X) is an advanced stellarator device operated in Greifswald, Germany, to provide the proof of principle that the stellarator concept can meet the requirements of a future fusion reactor by demonstrating high-performance, steady-state HELIAS operation. During the experimental programs, starting with the first operation phase OP1.1 (Dec. 2015 - March 2016) up to OP1.2a (Sept. 2017 - Dec. 2017) and OP1.2b (July 2018 - Oct. 2018), the energy input and plasma performance as well as the heat and particle loads on the in-vessel components were continuously increased. In these first OPs, the performance was limited because most of the in vessel components and in particular the divertor made of fine graphite elements was not water-cooled. During the experiments, high heat loads on the in-vessel components have been observed, which exceeded the specified limits under certain conditions, thus limiting the operation. In particular, significant baffle overload was detected in OP1.2 in the high mirror magnetic field configuration - the only configuration that meets all optimization criteria of W7-X. In addition to the baffle overload, an extension of the main strike-line to the middle divertor was observed in many configurations, resulting in high heat loads - larger than acceptable for the water-cooled CFC high-heat-flux divertor in the upcoming experiment campaign OP2.1 (start Nov. 2022). The installation of the water cooled divertor for OP2, which has the same geometry as the OP1.2 divertor, together with the cryo-vacuum pump system, has been completed in 2021. The purpose is to reach the defined goal of W7-X: 30 min long pulse operation with 10 MW plasma heating.
There is a general agreement within the W7-X project that the transition to reactor relevant materials for the plasma-facing components (PFCs) is an important and necessary step. The envisaged transition to an all-metallic PFC device requires a new design of the divertor components. The development of target elements with tungsten-based armor material designed to remove up to 10 MW/m2 in steady-state operation was started in early 2021 in the framework of EUROfusion.
Appropriate design changes taking into account various technical constraints need to be developed to optimize the current divertor geometry; a thorough evaluation and validation of the applied simulations against the experimental findings, as partially mentioned above, is being performed. The final goals will be the reduction of peak heat loads as well as high gas exhaust by divertor geometry and plasma scenario optimization.
This contribution presents first results of modeling activities for a new W7-X divertor using fast running tools such as the recently developed EMC3-lite for heat load analysis and an ANSYS application for exhaust studies to find favorable design changes, which are then verified with the comprehensive EMC3/Eirene and DIVGAS codes. These modeling activities are supported by the development of efficient engineering tools in a CATIA environment that process the complex 3D W7-X design data at different levels of sophistication to promote an efficient interchange with the physics-based codes. The impact of specific geometry modifications on divertor performance is reported.

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