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Advantage and disadvantage of the LHD heliotron divertor

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This paper discusses advantage and disadvantage of the LHD heliotron divertor in terms of divertor functions, such as neutral compression, impurity transport, and divertor heat load control.
The divertor plasma density in heliotron divertor stays at low values, ~1x10^19 m^-3, which never exceeds upstream density, i.e. at the stochastic layer, where ne can reach up to ~10^20 m^-3. This is interpreted as due to the strong magnetic shear at the edge stochastic layer, which squeezes and mixes up field lines of different connection lengths, and thus of different plasma pressures. The pressure loss through the enhanced cross-field interaction between the flux tubes results in low neutral compression in divertor region, ~0.1 Pa, even in closed divertor configuration. In order to compensate the low pressure, new cryo-sorption pump has been developed with an advanced technique on cryo-panels, which enables flexible shaping and compactness of the pumping system that can be installed directly under the dome structure in complex 3D shape. Pumping speed of 96.5 m3/s and capacity of 86,000 Pa m^-3 have been achieved so far, which can provide particle exhaust for low to medium density operations in LHD. Further upgrade for high density operation, ~10^20 m^-3, remains for future task.
The stochastic layer is distributed around the confinement region in all poloidal angles. Therefore, it provides effective screening against impurities coming from either divertor or first wall. VUV spectroscopy measurements with absolute calibration showed reasonably small impurity content in core plasma both for iron (~10^15 m^-3), which comes from the first wall, and for carbon (~10^17 m^-3), which comes from the divertor plates. EMC3-EIRENE simulations revealed clearly different features of impurity screening mechanisms between heliotron and tokamak configurations.
The divertor heat load is found to be strongly non-uniform along the helical strike lines, which overrides expected widening of wetted area due to the multiple strike lines and due to the double null divertor legs. On the other hand, because of the high density at the stochastic layer than the divertor region as described above, impurity radiation at the stochastic layer is main volumetric energy loss. Since Te at the stochastic layer changes from ~30 eV at the periphery to 300-500 eV at LCFS, this region has potential to provide various impurity line emissions. It is found that mixed impurity seeding of Ne and Kr, rather than single species, realizes stable radiative divertor operation and effective cooling of divertor plasmas. Control of edge radiation by RMP application has been also demonstrated, where radiation is enhanced around the magnetic island induced by the RMP. While these schemes are found effective to mitigate the divertor heat load, toroidal asymmetry in the heat load pattern appears during the detachment in certain operations. Core transport analysis shows changes in heat transport coefficient profile in the attached and detached phases, while no significant confinement degradation is observed.
Based on these results, prospect for further divertor optimization will be discussed.

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