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Effects of toroidal plasma current on divertor power depositions on Wendelstein 7-X

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Wendelstein 7-X (W7-X) stellarator has been optimized amongst other criteria for small bootstrap current. However, even small plasma currents can change the rotational transform (iota) and displace the magnetic island chains at the plasma edge, due to its low shear characteristic. Besides possible changes to the plasma core confinement, the power loads to the plasma facing components are affected, which is most important for divertor operation. Thus, scenarios with a small bootstrap current are crucial for W7-X [1].

W7-X has no transformer to drive an ohmic current. However, toroidal plasma current can arise as consequence of the intrinsic bootstrap current, but also by any additional externally driven current (e.g. electron cyclotron current drive (ECCD)) and the transiently appearing plasma shielding currents. The amplitude and radial profile of bootstrap current depend largely on the experimental parameters, e.g. magnetic configurations, heating power and plasma density. It is predicted in W7-X to reach values of up to tens of kA for high performance plasma discharges depending on the specific experimental scenario [2]. The evolution of toroidal plasma currents has been measured by a set of in-vessel Rogowski coils encircling the plasma volume, during the first divertor operation phase on W7-X.

For particle and energy exhausts in W7-X with its low-shear iota profile, the island divertor concept [3], which was tested successfully in W7-AS for the first time, has been chosen. It uses the naturally occurring island chains as interaction topology with the divertor targets. The super-conducing magnet system consists of 50 non-planar coils and 20 planar coils for additional flexibility as needed to change iota at the boundary of the vacuum configurations. For example, the so-called standard configuration has a boundary iota value of 1, which is accompanied by the 5/5-island chain forming the plasma limiting separatrix. The assessment of the interactions between the three-dimensional magnetic island chains and the divertor plates, which results in toroidally asymmetric but stellarator-symmetric power loads, requires a complete coverage of plasma facing component by real-time video diagnostics, which is also necessary for safe operation [4].

The methods to quantitatively analyze and visualize the heat loads on the divertor targets measured by infra-red cameras as well as to compare with diffusive field line tracing results have been introduced in [5]. To investigate the correlation between the experimental divertor thermal footprints and the measured toroidal plasma current, simulation results are used which are obtained with a field line tracer [6] available as web-service at IPP. To compare with experiments in this study with limited net toroidal plasma current < 10kA and volume-averaged beta-values $< 1\%$, vacuum magnetic field is used, and the toroidal plasma current is simulated using an ad-hot current filament on the magnetic axis.

In this study [7], the strike line movement caused by the increasing toroidal plasma current up to 6 kA has been observed and compared with simulations quantitatively. The ratio of the average movement to the value of the current is about ~9 mm per kA. Also, with increasing toroidal current, the vertical target is observed to receive more heat load than the horizontal target. We also observe the appearance of a second strike line, which is also seen in simulations. The simulations show that this is due to the heat transport from the outboard leg of the island, which is no longer shielded by other in-vessel components as the island chains moves towards the magnetic axis with increasing toroidal current. The observed reduction of the peak heat flux as well as the broadening of the heat flux profile on the horizontal target is mainly caused by the modified geometry of the island with increasing toroidal current. On the other hand, in the low-iota magnetic configuration, an inward shift of the strike lines with increasing toroidal current is observed.

This is consistent with simulations which show that the visible strike line is the outboard leg of the target intersecting island and the island displacement towards the magnetic axis moves the strike line to the inboard side. Experiments dedicated to ECCD have also been used for investigations of the strike line movements. Toroidal current being modified by ECCD shows similar strike line changes as the experiments with the freely evolving current. This suggests that ECCD may be a possible candidate for the strike-line control in the future.

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