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Predicting 3D heat fluxes of non-axisymmetric plasmas in SPARC tokamak with the HEAT code

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Despite the use of tailored plasma facing components (PFCs), the presence of non-axisymmetric (3D) field perturbations to the plasma magnetic equilibrium produces local peak heat fluxes that can lead to unacceptable temperatures when stationary, but might be maintained below a desired threshold when rotated. Therefore understanding the 3D effects that alter the heat flux patterns is essential for ensuring the longevity and heat-handling capability of the PFCs. The HEAT code [1], previously developed to simulate axisymmetric heat fluxes upon 3D PFCs, has now been expanded to be able to compute the heat fluxes due to 3D perturbations - calculated with the resistive MHD code M3D-C1 [2] - using a 3D heuristic heat flux layer model [3], which extends the 2D heat flux model also known as Eich-profile [4] to non-axisymmetric plasmas. In this work the new model, firstly validated against DIII-D data [5], is then applied to the SPARC tokamak, a compact high field machine that is expected to achieve peak unmitigated divertor parallel heat fluxes greater than 10 GW m−2. SPARC has 18 error field correction coils divided in three sets: one upper, one lower and one mid-plane. Although all of them can produce 3D fields, only those produced by a toroidal array of coils located at the outboard midplane and with an n=1 toroidal periodicity are considered in this work [6]. They are found to generate a secondary heat flux peak compared to the unperturbed case, whose intensity depends on the toroidal location (Figure 1), that lead to a strong toroidal asymmetry of the power distribution. Thermal analysis shows that - in absence of cooling by radiation - stationary 3D fields would quickly damage the PFCs, while rotating 3D fields, at a frequency as low as 0.5 Hz, could significantly reduce their temperatures. The potential for incorporating radiative cooling effects in the calculation is explored by coupling time dependent self-consistent plasma backgrounds, computed using the High-Order Finite Element transport code SolEdge-HDG [7], with HEAT. While these additions make the overall code more computationally intensive, the use of AI/ML [8] is also explored to speed up the calculations. First results showing the achieved capability to calculate 3D heat fluxes generated by axisymmetric plasmas in less than a second will be presented.

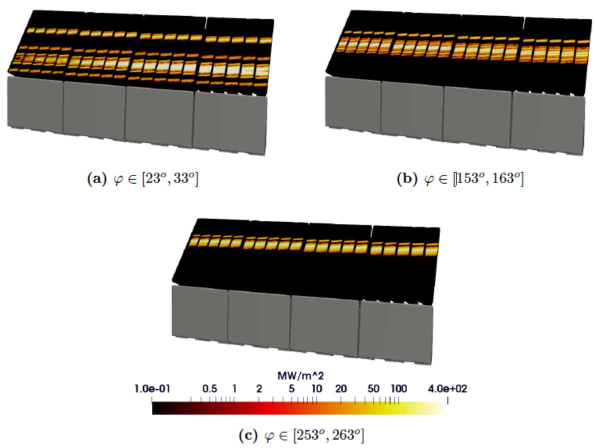

Figure 1. Simulated heat flux profiles along the lowest row of tiles of lower outer divertor of SPARC at three different toroidal sectors for $\lambda_q = 0.6\, mm, P_{SOL} = 29\, MW, I_{Coils} = 160\, kA.$

References

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