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Progress towards robust divertor and exhaust scenario optimization with SOLPS-ITER

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Divertor and exhaust scenario design for future reactors such as ITER and DEMO heavily rely on plasma edge codes as SOLPS-ITER [1]. In practice, the design process often proceeds through large parameter scans to explore the operational space, whereby divertor shape, magnetic field and model parameters are manually tuned to improve the performance of the design and meet various physics, engineering and material constraints. Combined with the complex and computationally expensive nature of plasma edge codes, this procedure is extremely cumbersome. Moreover, uncertainty on model and design parameters is often not accounted for explicitly.

Gradient-based optimization methods can significantly reduce the design effort, by automatically finding the design that optimizes performance, which is quantified by a cost function. Using adjoint techniques, the required design sensitivities are computed at a cost independent of the number of design variables. In the past years it has been demonstrated that these methods can be used to find optimal target shapes and magnetic fields minimizing the peak power loads towards the divertor based on somewhat simplified edge models [2]. In this contribution, we discuss recent progress towards enabling these methods for complex edge codes.

For efficient and accurate sensitivity computations in complex, continuously advancing codes, we use Algorithmic Differentiation (AD) which provides semiautomatic derivatives by direct processing of the source code. Both forward and adjoint modes of AD are applied successfully to SOLPS-ITER [3] using the TAPENADE tool [4]. Using these sensitivity tools, a wealth of information becomes accessible to the designer, allowing to identify the input parameters with largest impact on the solution, and providing full 2D sensitivity maps showing the spatial dependence. We use the same AD-based optimization algorithms in a Bayesian context to calibrate the model parameters based on experimental data [5], providing also information on the uncertainty distribution of the parameters. To enable divertor shape optimization in SOLPS-ITER, a grid smoothing tool is being developed to provide the necessary grids during the optimization. These achievements further open the way to robust design procedures, which optimize performance taking uncertainty into account.

A second challenge relates to accurate sensitivity evaluations in the presence of Monte Carlo noise from the kinetic neutral simulation. Without special measures, the sensitivities would be overwhelmed by the statistical noise. By differentiating the individual particle trajectories at fixed random numbers, however, reliable sensitivities are found [6]. AD has great potential in this context.

These optimization schemes are being integrated in the recently developed extended grids version of SOLPS-ITER, which also contains various enhanced model options to improve the accuracy and speed up individual edge simulations, optimization, and uncertainty quantification at the reactor scale.

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