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Efficient and rigorous evaluation of fast particle losses in non-axisymmetric tokamak plasmas

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We present novel techniques for fast-ion modelling that allow more extensive studies and support orbit-following modelling [1], and we apply those to study fast-ion transport in ITER.

While orbit-following Monte Carlo simulations are frequently used to make predictive estimates for fast-ion losses and wall loads, these simulations have the drawback that they are computationally expensive to perform. Furthermore, orbit-following tools are based on first principles and, as such, it is difficult to interpret which processes are responsible for the losses seen in simulations. This contribution addresses these issues.

It is shown that the collisionless transport of fast ions can be treated as an advection-diffusion process, where the transport coefficients can be evaluated with an orbit-following model. This results in a significant (a factor of 50 - 100) decrease in time that is required to estimate fast ion losses during the slowing-down process with an orbit-following model alone as the coefficients can be evaluated within just a few bounce times. With this approach it becomes possible to make an extensive study of fast-ion losses due to ITER ELM control coils using different current configurations. We vary the mode and poloidal phase of the coils and find the configurations where the losses have their minimum and maximum as shown in Fig.3. However, the study performed here is done in vacuum approximation while plasma response is needed for more accurate studies [2].

Another technique that is presented is the so-called loss maps where the birth position of particles, which are lost due to a 3D magnetic field, are mapped to a constants of motion phase space. We show that this mapping allows one to make the connection between different loss-mechanisms and the losses, thus increasing the confidence in one's results. Furthermore, we show that the particle birth position also predicts to which location on the wall it will be lost to. However, the main benefit of using the loss maps is that they can be constructed solely using the analytical formulas for different transport processes as exemplified in Fig.4. This provides a basically instant way of estimating losses, thus avoiding the need to resort to more time-consuming orbit-following simulations. The use of loss maps is demonstrated for ITER baseline and reduced field scenarios in the presence of various stationary magnetic field perturbations.

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[1] Särkimäki, K. (2020). Efficient and rigorous evaluation of fast particle losses in non-axisymmetric tokamak plasmas. Nuclear Fusion, 60(3), 036002.

[2] Varje, J., et al (2016). Effect of plasma response on the fast ion losses due to ELM control coils in ITER. Nuclear Fusion, 56(4), 046014

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