Equilibrium reconstruction of tokamak discharges with toroidal variation

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Equilibrium reconstruction is the essential tool for determining the field structure and current density in a tokamak discharge. For performance reasons, tokamaks are designed to provide a field structure which is close to being axisymmetric around the torus axis. Due to the limited number of toroidal field coils, there are however small deviations from the axisymmetry, the magnetic field ripple. We present a generally applicable algorithm for the calculation of the three-dimensional perturbed field due to the ripple.

The response of the plasma to a non-axisymmetric external field is difficult to obtain due to the nonlinearity of the equilibrium calculation. We consider tokamak discharges where the magnetic field is always dominated by the external toroidal field. This allows for applying an expansion with a small parameter related to the ratio of poloidal vs toroidal field component and the magnitude of the perturbation (Lo Surdo and Sestero 1975, Nucl Fusion **18**, 255). The algorithm gives the Grad-Shafranov equation in lowest significant order, and the perturbed plasma current as response to the toroidal magnetic field variation in the next higher order. This correction term is shown to be sufficient for those tokamaks where the deviation from axisymmetry is mainly caused by the field ripple. We present the implementation of the ripple correction for the equilibrium reconstruction code EFIT. The code is applied to discharges of the Tore Supra tokamak with 18 toroidal coils, resulting in a field ripple up to 7%, which has to be taken into account for precise equilibrium calculations. It is shown that the generalised algorithm preserves the convergence behaviour of the code and increases the computational cost only marginally. The results are compared with the real-time boundary code used for Tore Supra that uses an inverse mapping for the ripple correction. Both methods that use completely different algorithms agree on the position of the plasma boundary within a few millimetres. The code therefore serves as routine equilibrium analysis code for Tore Supra discharges. The algorithm is straightforward to implement for different tokamaks. We present a reconstruction for the ripple experiment on the JET device, where the ripple was generated on purpose by using half of the 32 toroidal field coils. We also propose the algorithm for ITER discharges, where the field ripple is not negligible in the present design.