

# TOROIDAL SIMULATIONS OF NONLINEAR THRESHOLDS AND SATURATIONS OF CLASSICAL AND NEOCLASSICAL TEARING INSTABILITIES.

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Experimental results in the past decade have revealed that neoclassical tearing modes (NTM's) in tokamaks are a substantial obstacle on the path toward thermonuclear fusion in magnetically confined plasmas. A precise understanding of the dynamics of these modes therefore is crucial, but requires full toroidal extended magneto-hydrodynamic (MHD) simulations. Solving this problem is a difficult task, first from the point of view of the physical parameters involved (in a tokamak plasma, the resistivity is about  $10^{-10}$ , the ratio of parallel to perpendicular thermal conductivity is about  $10^{10}$ , the dynamics of standard tearing modes (STM's) and NTM's is very slow compared to the dynamics of ideal MHD modes) and second from the point of view of numerics (the ideal MHD operator is ill-conditioned, its inversion by iterative methods is difficult, non-orthogonal metric complicate the algebra, etc.).

The XTOR code was developed taking into account all these constraints. In the past three years, it was successfully used to simulate the nonlinear stability thresholds of STM's and NTM's. These results led to a generalization of the Rutherford theory, describing the time evolution of the island size of both STM's and NTM's. In particular, the simulations with XTOR have revealed a nonlinear stability threshold for STM's, and, for a high enough plasma resistivity ( $S \geq \approx 10^6$ ) a linear stability threshold for NTM's [1,2]. Simulations with XTOR of the saturation of NTM's in the last few month once more refined Rutherford's theory.

The first resistive MHD version of the XTOR code proved the robustness of the semi-implicit time stepping method in resistive MHD for low pressure plasmas with circular poloidal cross-section [3]. Since then, the numerical method first was generalized to deal with ITER-like plasmas (high pressure, non-orthogonal metrics) and second includes more physics (parallel and perpendicular conductivity, bootstrap current term, time varying resistivity). Our results about the nonlinear full toroidal simulations of STM's and NTM's allow a straightforward presentation of all the numerical difficulties encountered during the development of the XTOR code.

[1] H. Lütjens, J.F. Luciani, Phys.Plasmas **9** 4837 (2002).

[2] H.Ltjens, J.F.Luciani, Phys. Plasmas **9** (2002) p.4837.

[3] K.Lerbinger, J.F.Luciani, J. Comp. Phys. **97**, 444 (1991).