Title : Numerical strategies for MHD instabilities: context of magnetic confinement fusion.

Abstract: The next step, a large-scale tokamak ITER device (International Thermonuclear Experimental Reactor) under construction in Cadarache in France, is to study the physics of burning D-T plasma magnetically confined in a tokamak device. ITER should prove that the exploitation of controlled fusion energy as a resource of electrical power is conceivable and that fusion power plants could be achievable before the end of the 21st century. In that case, the next step, DEMO, will be the prototype of what could later be a fusion reactor. Plasma confinement in the H-mode is considerably improved ("H" for high confinement) compared to a low confinement L-mode plasma typically observed below the L/H transition power threshold. H-mode is a primary baseline that can achieve fusion power gain. Note also that the maximum fusion plasma performance in terms of maximum plasma current, normalized plasma pressure ("beta"), and pressure gradient is limited in many cases by large-scale MHD instabilities. Hence, the achievable fusion power gain in ITER (and future fusion reactor DEMO), even in H-mode, will depend on these operational limits ruled by MHD activity. A significant edge pressure gradient accompanied by an enormous edge current density (so-called "bootstrap" current) are the typical conditions in an H-mode and are particularly prone to MHD activity. The pressure gradient and the current density are the two driving forces of the so-called Edge Localized Modes (ELMs), resulting from a coupling between kink (or peeling) modes driven by current and ballooning MHD modes driven by the pressure gradient. During their non-linear evolution, ELMs evacuate energy and particles rapidly through the separatrix so that the pressure gradient decreases and ballooning/peeling modes become stable again.

With this respect, the non-linear MHD theory can provide further physical and numerical improvements to refine knowledge of essential ELM dynamics and related ELM control techniques. Given the particular complexity of the problem, the numerical simulations provide a vital component of this effort since computations cost less than experiments when possible. Simulations combined with a well-focused, well-diagnosed experimental physics program assure numerical results' validity. Recent developments in plasma theory, computational physics, and computer science, along with anticipated advances in computer hardware performance, combine to make this simulation capability of non-linear MHD codes a desirable option to study ELM physics.

We will focus on the modeling and numerical strategies capability for non-linear MHD simulations of ELMs. Numerical stabilization compatible with the physical properties is the main challenging issue. Some well-established finite element codes as XTOR, NIMROD, and M3D, use stabilization techniques based on Taylor-Galerkin methods. The Taylor-Galerkin formulation is a class of more general sub-grid scale concepts. This strategy has been widely developed and recently applied for incompressible MHD. The main idea is to split the continuous solution of the problem into two components: the weak solution at a given scale and the subscales or subgrid scales, which are part of the solution that the discretization cannot capture. In this situation, the problem reduces to obtain a good approximation for the subscales. Many of these stabilizations depend on arbitrary algorithmic parameters, which need tuning to achieve the best accuracy possible. We will present optimized strategies with applications to JET, ASDEC, DIID, and ITER tokomaks geometries.