Non-linear gyro-kinetic Ion Temperature Gradient and Trapped Electron Modes turbulence modelling in X-point geometry with Resonant Magnetic Perturbations

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1.Introduction.The application of 3D magnetic fields such as Resonant Magnetic Perturbations (RMPs) demonstrated suppression/mitigation of Edge Localized Modes (ELMs) in many tokamaks, hence ELMs mitigation by RMPs will be used in ITER to prevent large transient heat and particle fluxes on the ITER divertor [1]. The understanding of ELMs and RMPs based on first principle modelling achieved significant progress during the last decade, mainly using the Magneto Hydro Dynamics (MHD) fluid approach [2,3]. However a number of experimental studies [4,5] have demonstrated that edge plasma turbulence also changes dramatically and hence should be taken into account in building the full physical picture of energy and particle transport during ELMs and RMPs.

2.Model. The non-linear resistive MHD code JOREK initially was developed to solve fluid MHD equations in toroidal geometry. The detailed description of the code including applications can be found in [2,3]. Recently the JOREK code was extended with a kinetic particles description that can be coupled to the fluid MHD approach depending on the application. In the present paper the non-linear electrostatic gyro-kinetic Ion Temperature Gradient (ITGs) and Trapped Electron Modes (TEMs) turbulence were studied in X-point geometry with the gyro-kinetic particle model within the JOREK code [3,6]. The details of the gyro-kinetic particle model used in this paper are given in [6], so here we only give a general idea. The particles are initialized to represent the density and temperature profiles with a Maxwellian distribution on the equilibrium grid and profiles obtained from the fluid MHD solution. Ions are treated in gyro-kinetic approach where ion gyro-centers trajectories are advanced using the RK4 method. The equation of motion of gyro-centers is solved in time varying gyro-averaged electric field [6,7] and time-constant magnetic field obtained from fluid MHD run for the corresponding application. Here we used non-linear MHD modelling results during RMPs and ELMs when magnetic topology, electrostatic potential and plasma profiles change significantly and in particular become 3D. In the present work electrons were treated in two approximations. In the adiabatic electron approach the electron density is expressed as a function of the electric potential [6,7]. Using this approximation ITG turbulence was modelled. In the kinetic approach for electrons we assumed that electrons follow the guiding center orbits since their Larmor radii are small, moreover the electron mass was taken only 100 times smaller than ion for numerical reasons ("heavy electrons"). With kinetic electrons both ITG and TEM turbulence can be modelled. Note that to treat electrons as kinetic one should use much smaller time steps in modelling. The number of particles and time steps used will be described below for each case. Typically we used about 10^8-$5x10^8$ particles (electrons and ions) and time steps 10^{-6}-$5x10^{-8}$s (larger time step for ITGs only with adiabatic electrons) to reach a saturated state after approximately ~2ms time. To transform the discrete particle distribution into a continuous representation on the finite element space the projection procedure was implemented using the same basis functions as in finite elements discretization as in fluid part of the code. The resulting system of equations is solved in weak form. After one time-step of all particles the quasi-