Linear and non-linear study of the $n = m = 1$ alpha particles induced fishbone MHD mode

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Analytical and numerical studies have been carried out to verify linearly the newly implemented 6D PIC module into the non-linear hybrid code XTOR-K [1],[2]. This code solves the two-fluid extended MHD equations in toroidal geometry while taking into account, self-consistently, kinetic ion populations. The verification has been performed by our new linear model and code [3], developed from [4],[5],[6]. It solves non-perturbatively the kinetic internal kink dispersion relation, with the particularity to take into account non-resonant kinetic terms and passing particles, which have revealed to be crucial features of the fishbone instability. Comparisons between our model and XTOR-K in its linear phase are presented, regarding the pulsation and growth rate (ω, γ) of the internal kink, and the position in phase space of the multiple resonant planes. As expected, the instability is stabilized on the kink branch and then destabilized on the fishbone branch. On the basis of this linear verification, a series of linear and non-linear runs have been launched with XTOR-K. Firstly a study of the alpha-induced fishbone instability on the ITER 15 MA equilibrium has been done. It highlights the linear thresholds of the instability in the diagram (q_0, β_h), with q_0 the on-axis safety factor and β_h the kinetic beta. The fishbone mode is found to be unstable for ITER relevant (q_0, β_h) couples. Secondly, a first non-linear simulation has been performed to study the non-linear evolution of the wave-particle interaction between the kink rotation and the alpha particle bounce and precessional motions on the fishbone branch. Such a simulation explores one limit described in [7], just above the linear threshold where MHD non-linearities dominate. Results show strong chirping of the fishbone mode associated with the alpha particle transport.

References

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