

Summary of papers presented in the Theory and Modelling session

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Abstract. A total of 14 contributions were presented in the Theory and Modelling sessions at EC-17. One Theory and Modelling paper was included in the ITER ECRH and ECE sessions each. Three papers were in the area of nonlinear physics discussing parametric processes accompanying ECRH. Eight papers were based on the quasi-linear theory of wave heating and current drive. Three of these addressed the application of ECCD for NTM stabilization. Two papers considered scattering of EC waves by edge density fluctuations and related phenomena. In this summary, we briefly describe the highlights of these contributions. Finally, the three papers concerning modelling of various aspects of ECE are reported in the ECE session.

1 Parametric effects

In a set of two presentations, E.Z. Gusakov and A.Yu. Popov analyzed three possible parametric decay processes for second harmonic X-mode waves in toroidal devices: ($t \rightarrow t' + \ell_{IB}$, $t \rightarrow \ell_{EB} + \ell_{IB}$, and $t \rightarrow \ell_{UH} + \ell'_{UH}$, where IB, EB, and UH, respectively, stand for the ion Bernstein, electron Bernstein, and upper hybrid waves). They found that the instability threshold could be substantially reduced (up to 5 orders of magnitude) if trapping of one or both daughter waves occurs preventing convective losses of the daughter waves. Such trapping is possible in a non-monotonous density profile as, for example in case of a hollow central density or in case of local density peaking inside a magnetic island, or in case of poloidal magnetic field inhomogeneity. The theory is proposed as a plausible cause for anomalous backscattering observed at TEXTOR and for ion acceleration and heating at TJ-II and TCV accompanying ECRH [1]. Confirmation of these theoretical proposals still requires more quantitative comparison with experiments.

2 Wave heating and current drive

In this category, there were four papers devoted to the modelling of operational scenarios using ECRH and ECCD. Within the ITER ECRH session D. Farina et al. presented a thorough analysis of the capabilities of the ITER ECRH equatorial launcher using the GRAY quasi-optical beam tracing code including the state-of-art CD package of Marushchenko [2]. The equatorial launcher is shown to be able to contribute to a wide range of ITER scenarios and fields, in all phases of the discharge. It

is suggested that the radial coverage of the system can be extended considerably by changing the poloidal rather than the toroidal steering of the current design. E. Poli et al. gave a talk on an assessment of ECCD-assisted operation on the DEMO reactor (under design). The major modelling tool in this work is his TORBEAM code which includes now the fully-relativistic absorption routines of the GRAY code and the state-of-art CD package of Marushchenko [2]. He found that under optimum conditions the figure of merit of ECCD can reach a value of $\gamma = R n_{20} I_A / P_{EC} \sim 0.3 - 0.4$ comparable or better than that of neutral beam current drive. This is due to the fact that the operational temperature of DEMO is about 50 keV and the broadening of the absorption spectrum of the O-mode EC waves at high electron temperatures. A talk on scenario modelling for the W7-X stellarator (under construction) was given by N.B. Marushchenko et al. He used his TRAVIS ray-tracing and current drive code coupled with VMEC (stellarator equilibrium code) and stellarator transport codes for performing simulations of various issues involving the operation of W7-X. The most important finding of the work is that the optimum ranges of magnetic field B_0 for start-up and steady state operation do not overlap. The adjustment of the magnetic field during high performance operation seems necessary. The last paper on scenario modelling was the poster presentation of L. Fignini et al. on the code benchmarking for ECRH and ECCD scenarios in ITER under the European Integrated Tokamak Modelling Framework. This is a new European version of Ron Prater's code benchmarking published in *Nuclear Fusion* 2008 [3]. A total of five European codes participated in this benchmark ranging from ray tracing and Fokker-Planck codes to quasi-optical and beam tracing codes. There is general agreement among predictions for the EC power deposition and current profiles. Some differences of these predictions are coming from differences in modelling of the EC wave propagation in the vacuum between the launching mirror and the plasma boundary. Y.M. Hu et al. gave a poster presentation which developed a relativistic model of ECCD efficiency based on Hirshman's variational principle. The model is similar to that of Marushchenko's [2] with a different set of variational basis functions.

3 ECCD for NTM stabilization

Another series of papers addressed the topic of neoclassical tearing mode (NTM) suppression by ECCD. These papers made more realistic modelling than the standard treatment. I. Chatziantonaki, et al. considered the effects of island geometry on the wave propagation, deposition, and current drive. The power deposition and current drive efficiency were shown, as expected, not to be significantly affected due to the small perturbations in magnetic field, plasma density, and electron temperature originated from island formation. Nevertheless, the instantaneous flux surface averaged absorbed power density and driven current density are greatly enhanced by the small flux surface volume of the magnetic islands. The correct account of these effects on the growth or suppression of NTMs, requires proper averaging of these current densities over the different phases of the island as it rotates through the EC power deposition region. An investigation along this line of thought was provided by B. Ayten and E. Westerhof. In their model, the instantaneous power deposition is calculated with account of island geometry and rotation. The driven current density, which is obtained through a simplified time-dependent current drive equation, is then incorporated into the modified Rutherford equation to determine the evolution of the island width. There are three time scales involved in the problem: τ_{coll} (collisional relaxation time), τ_{rot} (island rotation time), and τ_{NTM} (island growth time). The conventional approach averaging the ECCD over a full island rotation period is shown to be valid in the limit $\tau_{rot} \ll 0.01 \tau_{NTM}$, while $\tau_{rot} \gg \tau_{NTM}$ is identified with the locked mode regime. An increase of the averaged stabilizing effect was shown for $\tau_{rot} \sim 0.1 \tau_{NTM}$ and larger. J. Pratt and E. Westerhof reported plans to use the nonlinear reduced-MHD simulation code, JOREK [4] to study NTM dynamics more quantitatively in the future.

4 Wave propagation in the presence of density fluctuations

Finally, two papers were devoted to the study of the effects of edge density fluctuations on the propagation of EC waves and related phenomena. A. Ram gave an oral talk which emphasized the importance of these effects for ITER operation and discussed general theoretical approaches for dealing with wave propagation in such a random medium. J. Decker et al. gave a poster presentation of their work on this problem. They used an electrostatic turbulence model to describe the density fluctuations and ray-tracing techniques for wave propagation and deposition in successive perturbed equilibrium states. They concluded that the effects of fluctuations could improve the modelling of fully non-inductive ECCD discharges in the TCV tokamak: the edge scattering contributes can explain the current profile broadening and concomitant suppression of nonlinear effects as observed in the experiments. They also discussed implications of their theoretical results on the stabilization of NTMs in ITER.

References

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