EUROFUSION CP(15)05/27

D. Tegnered et al.

Gyrokinetic Modelling of Baseline H-mode JET Plasmas with C Wall and ITER-Like Wall

(22nd June 2015 – 26th June 2015)
Lisbon, Portugal

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Gyrokinetic modelling of baseline H-mode JET plasmas with C Wall and ITER-like wall

D. Tegnered[1], P. Strand[1], H. Nordman[1], C. Giroud[2], Hyun-Tae Kim[2], G.P. Maddison[2], M. Romanelli[2], G. Szepesi[2] and JET Contributors*

EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK

[1]*Department of Earth and Space Sciences, Chalmers University of Technology, SE-412 96 Göteborg, Sweden.* [2]*CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK*

Introduction

A deterioration in global confinement is observed at JET in baseline H-mode experiments following the change from a carbon wall to an ITER-like wall with beryllium and tungsten [1]. One cause is the high deuterium gas puffing rate necessary in ILW discharges in order to mitigate W accumulation. For low triangularity plasmas, this degradation of confinement with fuelling level was also observed for CW discharges [2]. The deterioration is correlated by a degradation of pedestal confinement with lower electron temperatures at the top of the edge barrier region. This leads to a lower electron temperature in the core, thereby changing the NBI heat deposition profiles in the core. As a result, the core energy confinement time is influenced with lower electron energy confinement time and similar ion confinement time in the ILW case [1]. To study the effect of the ILW on confinement, a database has been created comprising a set of JET discharges with ILW and matched CW discharges using the same criteria as in [3]. In the present work, transport due to Ion Temperature Gradient (ITG)/Trapped Electron Mode (TEM) turbulence is calculated for similar CW and ILW discharges using the gyrokinetic code GENE [4], in order to assess the differences seen in core energy confinement.

GENE simulations setup and discharge parameters

GENE solves the nonlinear gyrokinetic Vlasov equation coupled with Maxwell's equations. Collisions are modelled using a linearised Landau-Boltzmann collision operator [5]. Magnetic fluctuations are included in all simulations. The Miller geometry model [6] is used in a flux tube domain. Miller parameters are extracted from numerical geometries reconstructed by the EFIT code [7]. For the linear simulations both an initial value solver and an eigenvalue solver that can find subdominant modes are used. Two ILW discharges and two CW discharges with global parameters matched as closely as possible are analysed. The matched global parameters

*See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia are the plasma current, the toroidal magnetic field, applied NBI power, average electron density, safety factor, and triangularity. The discharges are baseline H-mode with ion temperature and rotation measurements available through charge exchange spectroscopy. Discharge parameters are taken from TRANSP runs [8] performed with electron density and temperature profiles from high resolution Thomson scattering measurements. One impurity species is included in the simulation, 1.9% carbon for the CW discharges and 0.4% beryllium for the ILW discharges. The impurity density is calculated from Z_{eff}, assumed constant over the whole radius [1]. The four discharges are analysed at $\rho = 0.5$ where ρ is the normalized toroidal flux coordinate. The discharges are pair wise 74313 (CW), 85407 (ILW), 74324 (CW) and 85406 (ILW). The data is averaged over a one second time window and smoothed in the radial direction.

Linear results

Due to the large uncertainty in the parameter R/L_{T_i}, the linear and nonlinear simulations of the ILW and CW discharges are performed as scans over R/L_{T_i}. The turbulence is ITG dominated for $R/L_{T_i} > 4$ for the ILW discharges and TEM dominated for lower R/L_{T_i} while for the CW discharges the TE mode is not excited. Thus, the discharges are all ITG dominated at experimental R/L_{T_i}. The ITG threshold is slightly lower for the ILW discharges and the normalized growth rates are larger at the same R/L_{T_i}. The ILW versus CW pairs considered are not perfectly matched with respect to dimensionless parameters. This leads to differences in linear stability of the main instabilities in the discharges. The reason for the mismatch in many parameters is related to the difference in pedestal height. This difference in the edge region translates into differences in the core of key parameters like β, Shafranov shift, and collisionality. These differences are expected to disappear if the pedestal confinement is recovered, e.g. through N seeding [9]. The difference in impurity content between the pairs leads to a slightly more stable situation in the C-wall case which should remain even if the pedestals are similar. In Figure 1, the effect of the difference in dimensionless parameters on the linear stability is summarized. The figure shows the relative change in the ITG growth rate when the values of the parameters in one discharge is changed to that of the corresponding paired discharge. As seen, the mismatch in β, Shafranov shift, magnetic shear, and electron temperature gradient serve to destabilize the ILW discharges relative to the CW discharges while the mismatch in collisionality and ion to electron temperature ratio tend to stabilize the ILW discharges. The difference in the safety factor and triangularity does

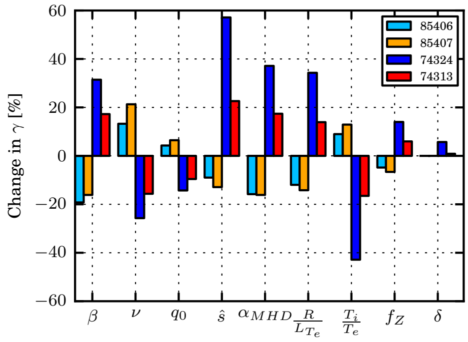
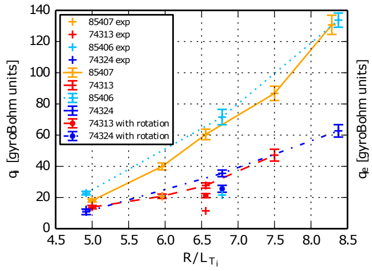


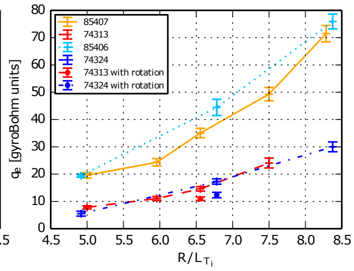
Figure 1: Growth rate change at $k_y\rho_s$=0.3

not substantially change the linear stability properties.

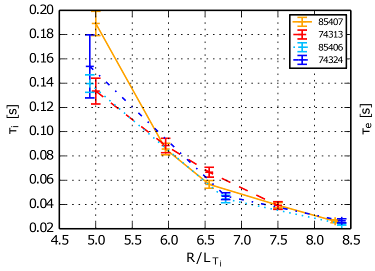
Nonlinear results



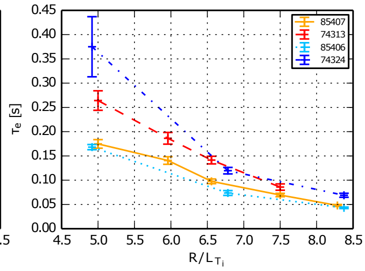
(a) Ion heat flux



(b) Electron heat



(c) Ion energy confinement times



(d) Electron energy confinement times

Figure 2: Nonlinear R/L_{T_i} scans, electron and ion heat flux and energy confinement times

For the nonlinear GENE simulations, a simulation domain in the perpendicular plane of $[L_x, L_y] = [146, 126]$ is used, with a resolution of $\left[n_x, n_{k_y}, n_z, n_{v_\parallel}, n_\mu\right] = [96, 48, 32, 64, 16]$. The resolution and simulation domain are checked through convergence tests. In order to quantify the effects of rotation, it was included in simulations of discharge 74313 and 74324. As can be seen in Figure 2a, this resulted in a reduction in the ion heat flux of around 20%. For these simulations, both the effect from the toroidal shear and Coriolis and centrifugal forces are included. Figures 2a and 2b show the scaling of ion and electron heat flux with R/L_{T_i} in normalized gyroBohm units. The electron temperature gradient is here fixed at the experimental value. An estimate of the stiffness is obtained from these normalized fluxes. As observed, the stiffness of the ILW discharges is larger than the matched CW-discharges. In non normalized units the heat flux for all the four discharges is comparable at the same R/L_{T_i}. The ion heat flux is larger than the electron heat flux as expected for ITG dominated discharges. In Figure 2a, the ion heat flux at $\rho = 0.5$ taken from the corresponding TRANSP runs is also shown. For the discharges at lower R/L_{T_i} the experimental heat flux is comparable with the simulated flux while for the discharges at higher R/L_{T_i}, the simulated ion heat flux is up to a factor ~ 3 higher. The discrepancy between the experimental and simulated fluxes can be explained by the uncertainty in the input parameters, in particular the uncertainty in R/L_{T_i} is large for the ILW discharges. The results follow the linear trends in that the linearly more unstable ILW discharges show significantly larger normalized fluxes. The electron energy confinement times are shorter for the ILW discharges while the ion energy confinement times are similar, as seen in Figures 2c and 2d, in line with the experimental analysis of [1]. The change is due to the difference in NBI heating power deposited to the electrons and ions in the ILW versus CW cases. The fraction of total NBI power deposited to the electrons is larger for ILW discharges as compared to the CW discharges. This is a result of the lower edge T_e in the ILW discharges.

Conclusion

The linear sensitivity scans showed that the relative change in key plasma parameters between the ILW and CW discharges had a significant effect on the ITG mode stability. The total effect of these parameter mismatches was that the ILW discharges were destabilized compared to the CW discharges at all $k_y\rho_s$. The nonlinear results followed the linear ones in that the ILW discharges showed higher normalized heat fluxes at both comparable and experimental R/L_{T_i}. The ion energy confinement times are similar, comparing the CW and ILW discharges while the electron energy confinement times are shorter for the ILW discharges which is in line with experimental analysis. These results indicate that the core confinement in the ILW discharges was affected by changes in key plasma parameters due to the degradation of the edge pedestal if compared to CW discharges. Hence, we expect the core confinement in the ILW discharges to be improved if the edge pedestals were recovered.

Acknowledgements and references

The simulations were performed on resources provided by the Swedish National Infrastructure for Computing (SNIC) at PDC Centre for High Performance Computing (PDC-HPC), on the HELIOS supercomputer system at Computational Simulation Centre of International Fusion Energy Research Centre (IFERC-CSC), Aomori, Japan, under the Broader Approach collaboration between Euratom and Japan, implemented by Fusion for Energy and JAEA, and on the supercomputer JUROPA at Jülich Supercomputing Centre (JSC). This work was funded by a grant from The Swedish Research Council (C0338001). This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

[1] Hyun-Tae Kim, M Romanelli, I Voitsekhovitch, T Koskela, J Conboy, C Giroud, G Maddison, E Joffrin, et al. *Plasma Physics and Controlled Fusion*, 57(6):065002, 2015.

[2] R Neu, G Arnoux, M Beurskens, V Bobkov, S Brezinsek, J Bucalossi, G Calabro, C Challis, JW Coenen, E De La Luna, et al. *Physics of Plasmas (1994-present)*, 20(5):056111, 2013.

[3] MNA Beurskens, J Schweinzer, C Angioni, A Burckhart, CD Challis, I Chapman, R Fischer, J Flanagan, L Frassinetti, C Giroud, et al. *Plasma Physics and Controlled Fusion*, 55(12):124043, 2013.

[4] F Jenko, W Dorland, M Kotschenreuther, and BN Rogers. *Physics of Plasmas (1994-present)*, 7(5):1904–1910, 2000.

[5] F Merz. *Gyrokinetic simulation of multimode plasma turbulence*. PhD thesis, University of Münster, 2009.

[6] RL Miller, MS Chu, JM Greene, YR Lin-Liu, and R. E. Waltz. *Physics of Plasmas (1994-present)*, 5(4):973–978, 1998.

[7] LL Lao, H St. John, RD Stambaugh, AG Kellman, and W Pfeiffer. *Nuclear Fusion*, 25(11):1611, 1985.

[8] RJ Hawryluk et al. *Physics of plasmas close to thermonuclear conditions*, 1:19–46, 1980.

[9] C Giroud, GP Maddison, S Jachmich, F Rimini, MNA Beurskens, I Balboa, S Brezinsek, R Coelho, JW Coenen, Lorenzo Frassinetti, et al. *Nuclear Fusion*, 53(11):113025, 2013.