Predictive simulations of reactor-scale plasmas fuelled with multiple pellets with the European Transport Simulator

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Introduction

Development of the operating scenario for fusion reactor requires integrated modelling addressing the critical reactor issues: plasma heating and fuelling, radiation from impurities, MHD stability, etc. Since all these issues are inter-linked, to demonstrate a successful operational scenario, the relevant physics need to be included in a single simulation. Thus, the environment used for scenario modelling should allow for the integration of multiple codes and physics modules into a single scientific workflow. The European Transport Simulator (ETS) [1] is an outstanding example of such an integrated workflow. The ETS workflow couples individual physics modules e.g. calculating the plasma magnetic equilibrium, deposition (by auxiliary heating systems) and transport of energy and particles, impurity radiation, and MHD. It offers several options of different fidelity for each physics component. Previously, ETS was verified against state-of-the-art transport codes and used to analyse data from existing tokamaks [2]. In this work, the capability of the ETS to simulate complex scenarios was used to study the possibility to control the plasma density in a reactor size machine by pellet injection.

DEMO scenario simulations with ETS

Present simulations were configured to reproduce overall plasma scenario developed by the system code PROCESS [3]. ETS was configured to solve the transport equations

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[*] See http://www.euro-fusionscipub.org/eu-im

for the current, the density (*for e, D, T, He, Ar and W*) and the temperature (*for e, D, T, He*). Temperatures for *Ar* and *W* were assumed to be equal to the temperature of deuterium ions. Transport coefficients were provided by the combination of Bohm-gyroBohm and neoclassical models, assuming the edge transport barrier at $\rho_{tor\_norm}=0.97$. Heat and current drive sources were calculated by the beam simulation package and α-heating module. Heat balance also included the radiation from impurities (*Ar* and *W*) and Synchrotron radiation.

The pellet module [4] used in simulations calculates the ablation rate of the pellet and provides flux surface averaged changes to density and temperature profiles, treated by the transport code as instantaneous event. In addition to the original model the current implementation includes *ExB* drifts following the scaling from ref.[5].

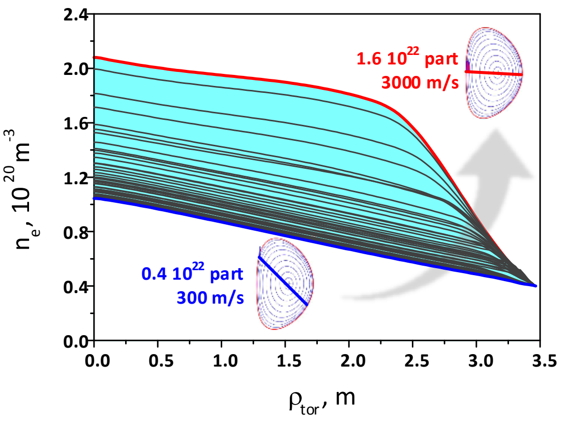

Fig.1 Pellet cycle averaged profiles of electron density for different injection locations, mass and velocity of the pellet

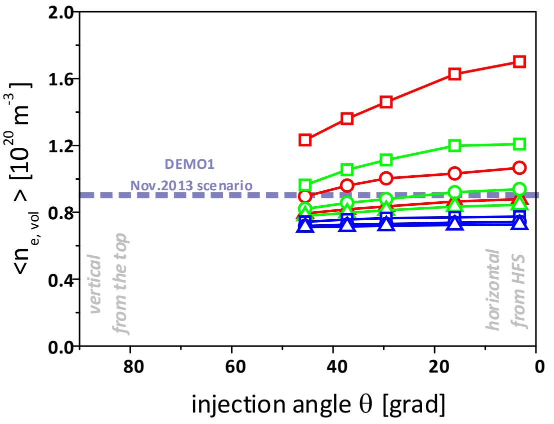

Fig.2 Steady-state volume averaged electron density compared to the requirements by DEMO scenario

Initial simulations were aimed in determining the domain of pellet parameters and injection locations, which might provide particle fuelling sufficient for maintaining the density in the reference DEMO scenario. Therefore, the simulations for five different poloidal angles of injection position, each with several pellet sizes and velocities were performed. To keep the particle throughput constant over the scan, the injection frequency was adjusted inversely proportional to the pellet size. As expected the fuelling efficiency increases over the scan with increasing velocity and size of injected pellets (see fig.1). This provides freedom on the pellet system optimization, where the reduction of the pellet size can be compensated by deeper penetration inside of the confined plasma. Nonetheless, a critical pellet size is found in simulations, below which the pellet injection system cannot provide the fuelling necessary to maintain the density required by the scenario considered for a fusion reactor. Figure 2 shows steady state volume averaged density versus the injection angle for the matrix of three different pellet sizes (**_4*10^{21}_**, **_6*10^{21}_** _and_ **_1.6*10^{22}_** _particles_) by three different injection velocities (_triangles-300 m/s, cycles -1000 m/s, squares-3000 m/s_). The required density can not be achieved with the smallest pellets under any conditions. For those pellets the ablation occurs at a very peripheral region, the majority of the ablated materials is expelled from the plasma before it can contribute to the fuelling. At the same time, simulations with larger pellets offer several possible solutions where the required density is achieved.

Therefore for next sequence of simulations the intermediate pellet of 6*10^{21} particles and velocity of 1000 m/s was chosen. In this group of simulations the flexibility of pellet injector design in terms of injection angle was addressed. The controller for the pellet injection was configured to maintain the volume averaged density required by DEMO scenario. For the same entry point at the vessel, the injection angle (_with vertical axis_) was varied between 10^{o} and 70^{o}, see fig. 3. Results of simulations are presented in fig. 4.

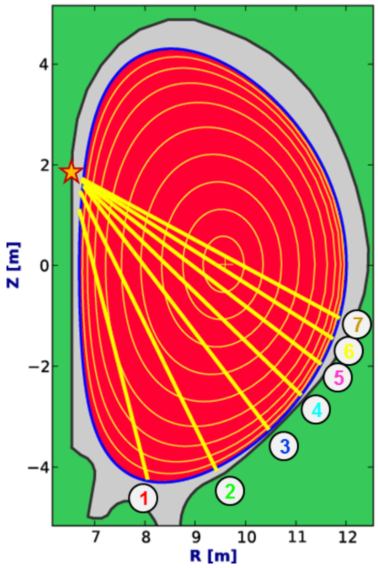

Fig.3 Pellet injection geometry

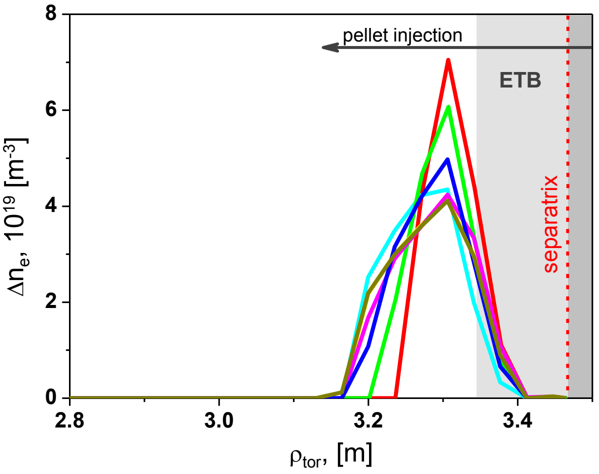

Fig. 4 Pellet deposition profiles for different injection geometry

The change of electron density profile caused by single pellet injection for different injection angles stays nearly the same for injection angles between 35^{o} and 70^{o}. For smaller angles the deposition shifts in the outward direction, when the fraction of the material deposited outside of the pedestal top increases. It makes fuelling less efficient and forces the controller to increase the frequency of the pellet injection in order to maintain the required density. Figure 5 shows the frequency of injection set up by controller at the steady state phase of simulated discharge (_when required plasma_ *parameters are achieved*) as a function of injection angle. These results show the flexibility for the design of the pellet injection system for DEMO

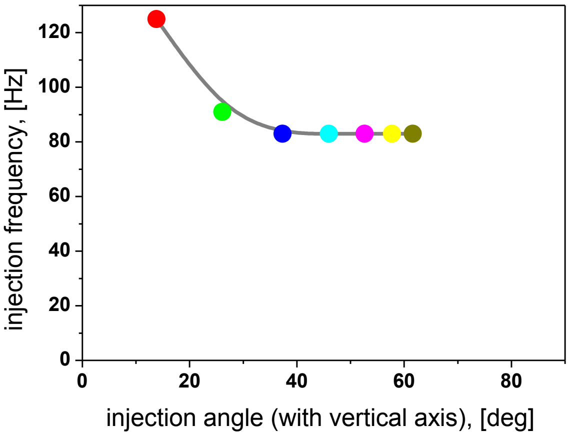

Fig.5 Output from pellet injection controller: adjustment of the injection frequency depending on the injection angle

Conclusions & Remarks

The European Transport Simulator has reached a mature state and can be applied for complex scenario simulations, eg for predictive simulation of reactor scale plasmas. The density for the foreseen DEMO operational scenario can be maintained by medium size pellets injected from the high field side. The injector design allows for some flexibility in choosing the pellet speed and injection geometry keeping the same fuelling efficiency. The computations presented do not include stability analysis of the MHD, whereas it might cause additional physics limitations in optimizing the pellet parameters, especially for largest pellets. Integration of the MHD stability chain into the ETS is foreseen as a next important development of the simulation package.

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The results presented here, obtained using the EU-IM framework, present an integrated modelling exercise testing and verifying the consistency of dedicated physics actors. They are not (yet) meant as a basis for decision making on the design and parameters of the DEMO PELLET system.