Divertor plasma shaping and modelling of ASDEX Upgrade

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1. Introduction

The power handling capability is a crucial problem in toroidal magnetic confinement fusion devices. The maximum tolerable stationary heat flux is limited by the active cooling efficiency. The limit for transient heat fluxes is given by the maximum tolerable surface temperature. A way to reduce the plasma power loads on divertor targets without changing the overall plasma shape is to decrease the impact angle of the separatrix on the targets by using shaping coils. The object of the present study is to investigate the operational space of AUG (ASDEX Upgrade), in terms of incidence angle flexibility in order to reduce the divertor power load in H-mode plasma using a coupling of CREATE XSCTools [1] with EDGE2D/EIRENE [2]. The AUG strike point incidence angles on divertor targets are varied by keeping as much as possible frozen the plasma shape and the main plasma parameters of interest, such as (l_i, β_{pol}, I_p). In this paper the results of modelling activity of the AUG SOL/edge plasma, including heat loads on the divertor, are reported, together with the very preliminary experimental results. The paper is organized as follows: in section 2 the computing tools used to reconstruct the reference plasma shot #25374 and produce the modified equilibria are described; in section 3 the plasma reference shot and the setup of EDGE2D is briefly described; in section 4 the results of the simulations performed with EDGE2D are discussed together with the presentation of preliminary results in getting the magnetic configuration.

2. Equilibrium reconstruction and shape modification

Plasma shape modelling is based on linear and nonlinear tools, CREATE-L [3] and CREATE-NL [4]. The CREATE-NL code is a finite element code that simulates the MHD time evolution of 2D axisymmetric plasmas in toroidal nuclear fusion devices, like tokamaks, in the presence of current and/or voltage driven circuits, of currents induced in the passive conductors, of forced and/or free plasma shape parameters (l_i, β_{pol}, I_p) and of a total plasma current. These tools are aimed at providing reliable plasma response models for control system design and assessment. The first step for the construction of the model is the definition of an equilibrium configuration in terms of desired plasma boundary, poloidal flux at the boundary, poloidal beta, internal inductance and total plasma current. This step is accomplished using an inverse version of the CREATE-NL code. The result of this step is then processed to get a forward equilibrium and a linearized response model. This task is carried out independently by two distinct tools: CREATE-L and the equilibrium-linearization section of CREATE-NL. The XSCTools suite consists also of another code, CREATE-EGENE, a linearized forward/inverse equilibrium generator that allows the user to start from the initial plasma shape and move towards a new one changing several boundary descriptors, including the plasma the shape and the strike points location. For any new setup, CREATE-EGENE displays the needed PF current. Two modified equilibria, with quite different strike point location, have been obtained from a reference H-mode AUG discharge, keeping the plasma internal parameters (l_i, β_{pol}, I_p) fixed to the reference value, i.e. 0.83 1.03, and 0.8MA respectively; moreover the complete plasma shape has been kept frozen, within the actuator limits for the currents flowing in the AUG PF coils.

3. Setup of EDGE2D runs

The EDGE2D grid is derived from the magnetic flux surfaces of pulse #25374 obtained with the magnetic equilibrium reconstruction at 3 s using CREATE-NL equilibrium code. The grid has 81 cells poloidally, 48 radially and extends about 20 cm inside the separatrix and 4 cm outside. Input power is equally shared between ion and electron channel. All cases are run without drifts. Experimental gas puffing ($5\cdot 10^{21}\,s^{-1}$) from outside is used to control density. It is to be noted that the interpretive EDGE2D modelling, with respect to the fitting of experimental outer mid-plane ne, Te and Ti profiles, gives a large degree of freedom regarding a possible choice of theoretical models for the perpendicular transport. Good quality measured mid-plane density and temperature profiles, as well as several other parameters and profiles measured in the divertor, enable the consistency test of code solutions against experiment. Using external boundary conditions from the experiment, the perpendicular heat conductivities $\chi_{i,e}$ and the particle transport coefficients D are varied until good agreement between code result and measured data was obtained. These are set to give the best possible match to the experimental outer target profiles whilst still being within the constraint of the upstream T_e and n_e profiles. The time-dependent effect of ELMs on the edge profiles was simulated with an ad hoc ELM model based on the repetitive increase of the transport coefficients $\chi_{i,e}$ and D. In code simulations, of primary importance for prediction of the outer divertor plates parameters are the match with experimentally measured upstream profiles and boundary conditions such as particle and power input into the numerical grid, radiated power and details of the neutral pumping system. The Albedo is set in order to get the same speed, the particle are pumped with, in the experiment, i.e. 25 m^3s^{-1}. The same numerical grid, with some slight changes due to the different flux lines in the divertor region, is used for the two modified equilibria.

4. Results and conclusions

Both position and incidence angle of the strike points on the divertor targets have been varied and two modified equilibria have been produced and then analyzed with EDGE2D: case A (magenta in Figure 1) with a reduction (with respect to the reference case) of the separatrix incidence angle on the outer target of 7°; case B (green in Figure 1) with an increase of the separatrix incidence angle on the outer target of 1.6°. The XSCTools were able to design modified shapes with a good flexibility: the two strike points can be moved several centimetres upwards and downwards with respect to their reference position. Numerical simulations have been performed to predict the power loads on the targets given the same experimental boundary conditions. Within the present study the extension of XSCTools to AUG fusion device to provide linearized models has been obtained. Starting from the reference plasma shape reconstructed with XSCTools the plasma discharge has been designed in order to get in the same shot the reference shape and modified ones :1.4s - 2.4s case B, 3.4s - 4.4s reference shape and 5.4s - 6.4s case A). With respect to the reference plasma shape preliminary EDGE2D simulations predicted an increase of the power load on the outer target for case B; as well, for case A a reduction of the power load was predicted. Very recently some dedicated shots were run on AUG to verify the capability of the

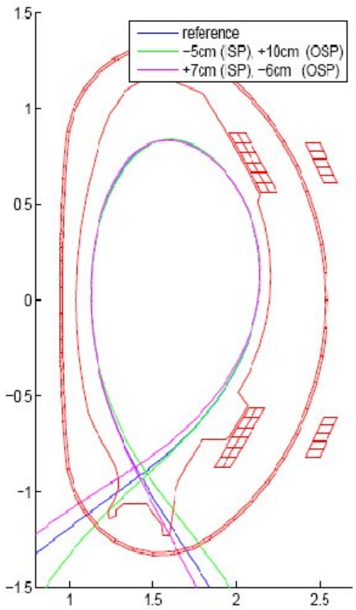

Figure 1: Reference equilibrium 25374@3s and mofified shape

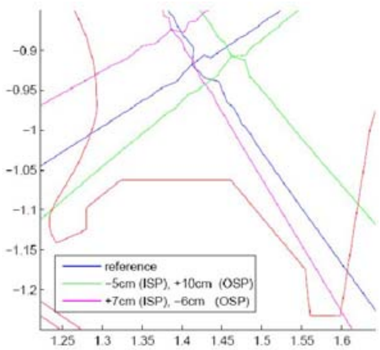

Figure 2: Zoom below the X-point

XSCTools to move strike points and modify their incidence angles on the divertor target whilst leaving the rest of the plasma frozen. The time traces of the main experimental signals for plasma shot #27115 are shown in Fig. 3. The line-averaged density was ~5.8_$10^{19}$$m^{-3,}$ corresponding to ~60% of the Greenwald density limit. The density was maintained with gas fuelling at NBI of 5 MW. The preliminary analysis of experimental results is ongoing.

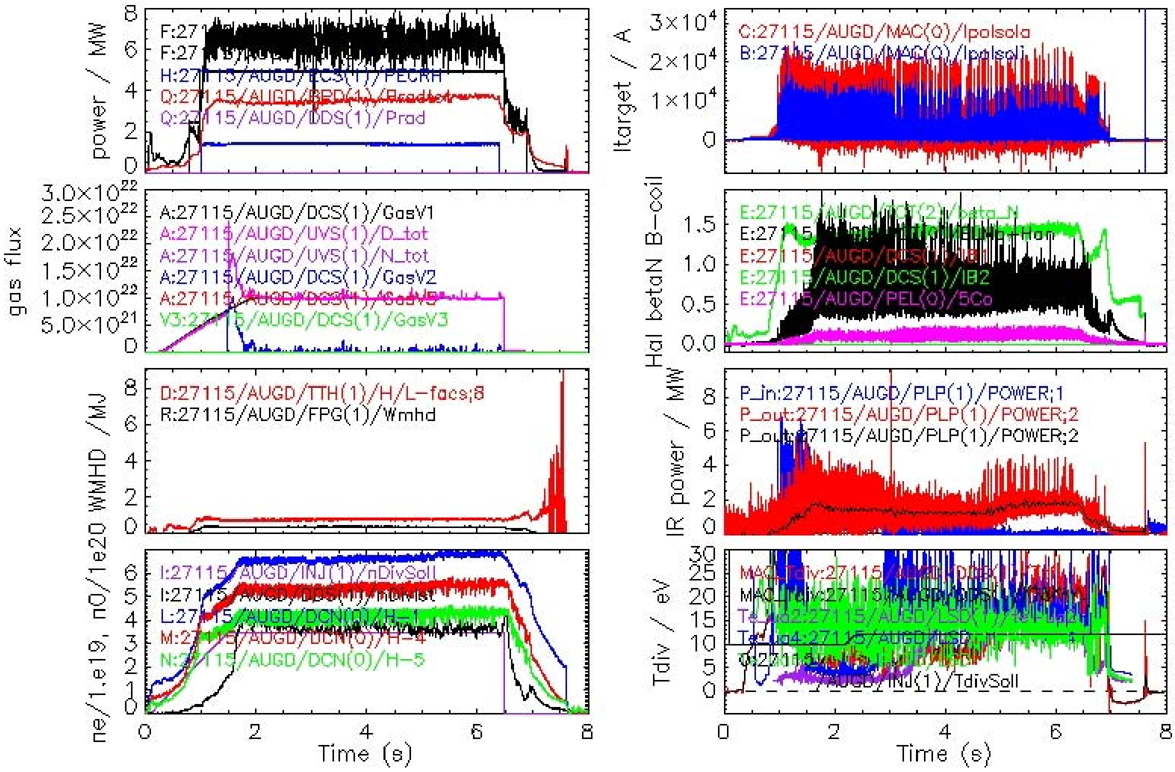

Figure 3 Time traces of plasma shot #27115

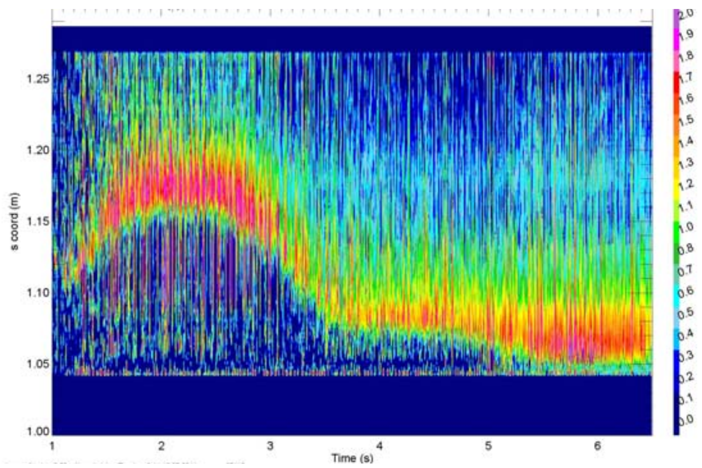

Figure 4: Poloidal position of the outer strike point footprint as a function of time

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