EUROFUSION CP(15)05/11

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(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.

TECXY modelling studies of alternative EAST magnetic configurations

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Introduction

Several alternative magnetic divertor have been imagined to handle high exhaust power. Many of them rely on the presence of a second null, more or less close to the first one. The main physics difference being whether the flux line are converging or flaring in front of the divertor plates. Several authors refer to experimental scenarios dedicated to understanding the role of the two nulls as quasi Snow Flakes (QSF) scenarios, so we do in the rest of this paper. The first experiments [1, 2] on the Experimental Advanced Superconducting Tokamak (EAST) were mainly devoted to study the feasibility of the QSF configurations for different distances of the two nulls. This contribution reports on predictive and interpretative simulations focusing on the comparison of QSF versus standard single null configurations (SN). Consistency is found between the experimental and calculated mitigation of the power load onto the divertor targets for QSF at low scrape-off layer (SOL) density and low additional power. Predictions on how further mitigation can be achieved at high density will be presented together with preliminary studies on the reciprocal distance between the two produced nulls.

TECXY interpretative simulation results

For its very high flexibility and possibility to easily perform parameters scan, TECXY code [3] is the modelling tool chosen to study the EAST's edge plasma. It takes into account all the main physics processes occurring in the SOL, but simplifies the neutral dynamics using an analytical model instead of the more rigorous Monte Carlo method. In addition, the divertor plates are always assumed to be perpendicular to the flux surfaces and the private flux region is neglected. The large saving of computational time implied by the above simplifications motivates this choice when general trends and/or global comparisons of different scenarios are searched for and/or when a preliminary optimization/exploration of the operating parameter space is attempted. This is especially true when alternative complex configurations have to be analyzed, and several parameters quickly varied to have the basic relative idea about the role of each parameter. In our case the most important point being the exploration of the reciprocal distance of the nulls, compared to density and power variations. Moreover, TECXY agrees with the results of more sophisticated codes within its application limits described just above, as discussed in [5, 6]. In this section we use TECXY to find out the zero order differences experimentally found between the QSF and SN features, discharges #48971 and #47038 respectively. Their shapes reconstructed by the equilibrium code are shown in Fig. 1. For QSF #48971 it is: t=4.5s, $\beta_p = 0.76$ and $l_i = 1.28$, the distance of the secondary X-point from the primary one is 70 cm. For SN it is t=4.5s, with $\beta_p = 0.58$ and $l_i = 1.56$. The main quantities used as input for the TECXY calculations are experimentally determined as follows. 1) input power to the SOL: P_{SOL} = 431.7 kW for SN and P_{SOL} = 414.5 kW for QSF case, which has neutral beam auxiliary power $P_{NBI} = 513.8kW$ but a slightly higher radiation; 2) electron density at the outer mid-plane (OMP) separatrix $n_{e,LCMS} = 6 \times 10^{18} m^{-3}$ for both discharges. No dominant impurity has been considered since, as mentioned above, here we are only looking for the zero order effects and since we are not concerned with absolute predictions, but with comparing the relative behaviour of two similar discharges The P_{SOL} fraction deposited on the plates is quite similar at this density, 51% for the SN and 46% for the QSF. Almost all the mitigation for QSF has to be attributed to the flux expansion (FE). For these rather low densities, a very similar trend was found in previous studies [7] with EDGE2D/EIRENE run for comparison purposes with TECXY. In Fig. 2 the power density measured by the infrared (IR) camera diagnostic on the lower outer target is shown versus the distance along the target and compared to the simulated heat loads. Corrections for the actual target tilting have been applied. From the qualitative point

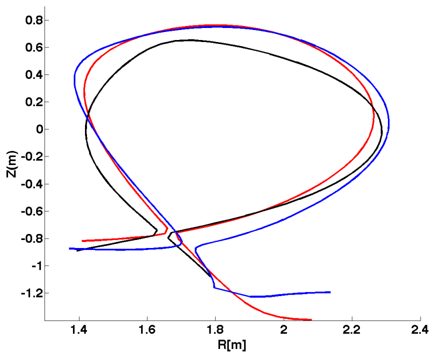

Fig. 1: Plasma boundary of the analyzed equilibria the experimental QSF (red line), reference SN equilibria (black line) and the QSF with close nulls (blue line)

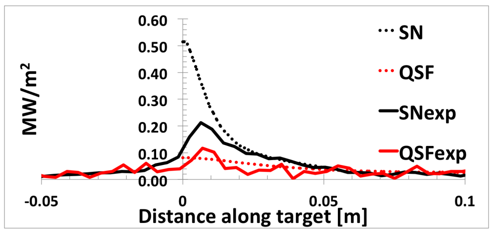

Fig. 2: Head load flux on the outer target: comparison between IR thermography data (solid lines) and TECXY simulation (dashed lines).

of view the code well reproduces the profile shapes and measured power mitigation in QSF. The largest quantitative discrepancy refers to the peak values of SN. A strong candidate for this is the diffusion into the private region, not included in the calculations. Indeed the differences of the integrals over this region are consistent with the integral of the experimental curve on the left side of the graph. This effect should be much less pronounced for smaller gradients that develop with QSF. Therefore, this could also account for the discrepancy in the resultant mitigation. Conversely, the QSF discrepancies could be attributable to experimental inaccuracies. This matter is presently under further investigation. A recent upgrade of TECXY would also allow to consider the private region, too.

TECXY predictive simulation results

A power and density scan have also been carried out to better study the behaviour of the actually realized configurations in different scenarios, as far as target load and volume losses are concerned. Three different values of P_{SOL} and $n_{e,LCMS}$ have been considered: $400kW$, $1.5MW$ and $3MW$ for the SOL input power and 3, 6 and $8.8 \times 10^{18} m^{-3}$ for the SOL outer mid-plane density. In Fig. 3 the mitigation factor (ratio of the SN to QSF peak load) is plotted versus $n_{e,LCMS}$ for the three P_{SOL} values. The experimental datum is also shown. As previously found for the proposed tokamak FAST [7], high SOL density can exalt the load mitigating properties of the QSF, as evidenced by the 400 kW data (black squares). The reason has been recognized into the higher volume losses when the connection lengths are strongly increased as it occurs in QSF. Clearly high volume losses develop as a macroscopic effect if a non-negligible loss already exists with SN, namely if the SOL conditions do allow any volume losses to occur. This is instead prevented if the power flowing into the SOL is increased so that the temperature grows too high where the largest difference in the connection lengths is found. This occurs already for 1.5 MW: in this experimental situation, by further increasing the plasma current and density, a similar behavior it would be reproduced. A further step in the investigation of the alternative configurations that are realizable by the PF coils system of EAST has been to study a QSF A

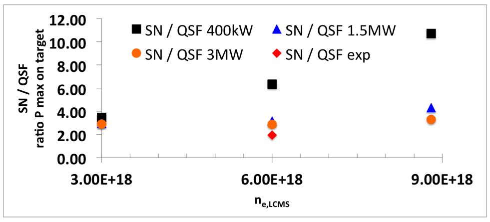

Fig. 3: Predictive power and density scan based on the experimental SN and QSF equilibria

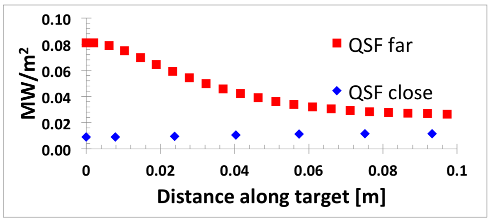

Fig. 4: Comparison of the power density calculated by TECXY at the outer target for the two QSF equilibria, $n_{e,LCMS} = 3 \times 10^{18} m^{-3}$

further step in the investigation of the alternative configurations that are realizable by the PF coils system of EAST has been to study a QSF configuration with close nulls (QSFcn), shown in Fig. 1 . The purpose of this configuration is to further prolong the connection lengths and also to shift the second null towards the primary X-point. In this configuration the proximity of the secondary null, only 43 cm far from the primary one, increases the connection length, evaluated at the outer target plate, from 33 m of the SD to 110 m (75.6 m in the experimental

QSF, QSFexp). Also a significantly larger FE is generated. If we quantify the FE as the target to OMP ratio of the poloidal distance of the flux surfaces from separatrix, we obtain for SD, QSFexp and QSFcn respectively the values of 3, 10 and 33. Furthermore by comparing the poloidal flux we see that for the QSFexp we obtain a monotonic decrease (contracting), (SF like, when a second null is present) whereas for QSFcn a flaring (XD like [4]) of the flux tubes. The predicted power load by TECXY on the outer target for this case is compared in Fig. 4 with that of QSFexp for $n_{e,LCMS} = 3 \times 10^{18} m^{-3}$ and P_{SOL} =414.5kW. The peak of the profile is reduced by more than 4 times, i.e. more than implied by the expanded flux ($\sim$ 3 times).

Conclusions

The first experimental QSF configuration has been obtained in EAST tokamak by creating a far secondary X-point, allowing to increase the connection length by $\sim$ 30% and the FE in the outer divertor region by a factor $\sim$ 4. IR camera measurements have been compared with those obtained in a similar conventional SN configuration and have been interpreted with the TECXY edge code. The general trends are reproduced for the different magnetic configurations. The profiles are well reproduced except in the close proximity of the strike point, but the discrepancies can be explained by having neglected the private region. The heat load mitigation is almost entirely due to the FE since the low working density is not suitable for enhancing significantly the volume losses, achievable by increasing the connection lengths. Predictive studies confirm that a reduction in the total load should be observed at higher densities, the exact value of which however depends on the power flowing into the SOL. Indeed higher power can increase the SOL temperature and hinder the dissipative processes. In addition a QSF configuration with close nulls that can be realized with the PF coils system has been modelled with TECXY. The potentiality of this configuration in affecting the power exhaust more efficiently than the QSF just realized is evidenced.

Acknowledgments

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