Comparative study of a conventional, Quasi-snowflake and Liquid Lithium divertor for the DTT (Divertor Test Tokamak) tokamak

G. Rubino[1] , B. Viola[1]

[1] *ENEA, Fusion and Nuclear Safety Department, C.R. ENEA Frascati, CP65, 00044 Frascati, Italy*

Introduction

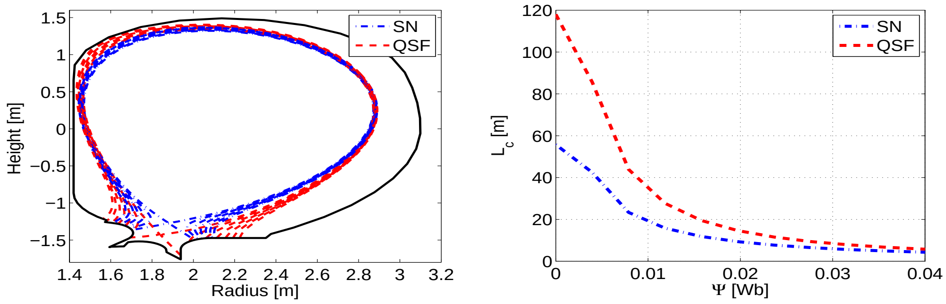
The EUROfusion consortium, and in particular the two dedicated Work Packages WPDTT1 and WPDTT2, are currently assessing the possibility to adopt alternative divertor solutions in order to mitigate the power load onto the target plates of fusion tokamak devices. The Quasi SnwoFlake (QSF, as defined in [1]) divertor has been suggested as one of the possible solutions. A change in the divertor magnetic topology is obtained by introducing a second null far from the first null of B_{pol} in a Single Null (SN) configuration. As a results, the flux surfaces in the poloidal plane are more expanded compared to the conventional SN, which in turn leads to an increase in the connection length, in the divertor volume and in the wetted area[2].

We present in this work a preliminary comparative study of a conventional SN and a QSF configurations for the DTT (Divertor Test Tokamak) tokamak machine, a new tokamak test facility proposed in the framework of the EUROfusion program for studying the power exhaust problem envisaged in the Demonstration fusion power plant (DEMO)[3]. Thanks to the high flexibility, DTT is particularly suited for the study of a wide range of divertor configurations in DEMO relevant conditions. Preliminary comparisons have been carried out with the 2D edge code TECXY[4] and reported in [3]. The numerical predictions show that in case of SN configuration the power peaks on the targets are not sustainable, while reaching a manageable values in case of QSF configuration. In this paper we will discuss the results obtained by means of the EDGE2D-EIRENE [5],[6],[7] code by considering the same condition as in [3]. The results of the numerical simulations will be discussed in terms of heat power load and global trends for the SN and QSF, identifying the main driver for the different behaviour of the two configurations.

Magnetic topology

As mentioned, the QSF configurations is featured by the presence of a second null point in B_{pol}. As a consequence, the poloidal field surrounding the X-point in QSF is very low compared to the SN case, i.e. the field lines are aligned almost toroidally. This feature reflects in an increase of the connection length L_c and in a widening of the flux surfaces in the poloidal plane. The different shape of the flux surfaces and the effect of the second null point is clearly visible in

Fig. 1 panel (a), where a sketch of the two magnetic equilibria is shown, and panel (b), where the two different $L_c s$ as a function of the flux coordinate are given.



(a) (b)

Figure 1: (a) Sketch of the SN and of the QSF showing the flux surfaces in the poloidal plane. (b) Connection length for the two magnetic configurations as a function of the flux surface coordinate.

Clearly, closer the flux surfaces to the separatrix, higher the effect on L_c,with a maximum of $L_{c,QSF}/L_{c,SN} = 2.11$. Therefore, the different topology has an intrinsic mitigation effect on the power exhaust. On one hand, the enlargement of the flux surfaces spreads the heat power of the relevant flux tube over a larger area than in SN case, since the parallel heat flux should preserve in absence of dissipation effect. On the other hand, the increase in L_c means a longer particle dwell time τ_{dw} allowing particle and energy to diffuse deeper in the Scrape-Off Layer. Collectively, the mitigation effect caused by the geometrical properties of the QSF can be taken into account by considering the ratio $f_r = \sqrt{L_{c,QSF}/L_{c,SN}}\,\Delta x_{QSF}/\Delta x_{SN}$, where Δx is the poloidal distance between two adjacent flux surfaces. This ratio should be compared to the reduction power peaks obtained in the two configurations $f_r = q_{0,SN}/q_{0,QSF}$.

SN and QSF results

Both for QSF and SN configurations we have considered three different volume averaged densities $1.0, 1.8$ and $2.5 \times 10^{20} m^{-3}$, which correspond to low, reference and high density scenarios with outer midplane separatrix density of $n_{e,LCMS} = 0.5, 0.75$ and $1.0 \times 10^{20} m^{-3}$, respectively. EDGE2D-EIRENE has been setup to simulate the standard H-mode scenario, described in [3], wiith an auxiliary power of $P_{aux} = 40MW$. We considered a pure Deuterium plasma, imposing a power crossing the separatrix $P_{SOL} = 36.8MW$. The diffusion coefficients for particle and energy, given as input to the code, has been chosen to get a power decay length $\lambda_q \approx 3mm$ and has been set to $D_\perp = 0.15m^2/s$ and $\chi_e = \chi_i = 0.35m^2/s$. The particle sink is imposed by defining a pump, located in the private region, with an assigned value of the albedo $\alpha = 0.94$ physically linked to the recycling.

Table 1: Summary of the results for QSF and SN configurations with $P_{SOL} = 36.8MW$.

	Single null			Quasi Snowflake		
$\Delta x[cm]$	1.8			10.6		
$n_{e,LCMS}[10^{20}m^{-3}]$	0.5	0.75	1.0	0.5	0.75	1.0
$P_{peak,OT}[MW/m^2]$	148	91	64	17.3	14.8	9.6
$P_{tot}[MW]$	35.2	22.52	17.7	28	22.5	17.4
$P_{loss}[MW]$	1.7	14.2	18.9	8.7	14.2	19.3

The global results of the simulations for the three different density scenarios are given in Table 1. In QSF case a high reduction of the peak power is observed (Fig. 2), reaching manageable value also for low density, while in case of SN the power peaks remain much beyond the tolerable values even in case of high density. However, both total power loads onto the targets and power losses are similar in the two cases, except for the low density case. This behaviour indicates that the most important mitigation effect predicted in the QSF configuration is driven by the topological effect rather than by an increase of the radiative losses, related to the high temperature field near the X-point where the difference in L_c is more pronounced. This behaviour is confirmed by the role played by the radiated power that remains low in both configurations and reaches $\approx 10\%$ of P_{SOL} for $n_{e,LCMS} = 1 \times 10^{20}m^{-3}$. Conversely, the ionization and molecular dissociation contributions are important in the power losses balance and have similar value in the two configurations. Similarly, the charge exchange contribution is high although it remain almost constant in the three density cases and slightly higher in QSF, probably due to the higher L_c than in SN. As mentioned, we can compare the ratio $f_r = q_{0,SN}/q_{0,QSF} = 8.5, 6.1$ and 6.7 for the different cases to the topological value $f_r = 7.76$. This is a further confirmation of the pivotal role played by the geometry and, in particular, by the widening of the flux surfaces.

The power density profiles onto the outer target for QSF (solid symbols) and SN (open symbols, divided by 10) are shown in Fig. 2. The effect of the different flux expansions is clearly evident: the power profiles in QSF cases are more flat than in SN allowing a reduction of power peaks, while keeping similar integral values. In particular, because of the different Δx as reported in Table 1, in case of SN the power load is mainly deposited in a small area close to the separatrix (few cm), while a broadening of the power profiles is seen in QSF. Finally, it is worth to note that the detachment regime is not reached in both configurations. The results shows that the starting of the detachment without impurity in QSF is achieved for density close to the high

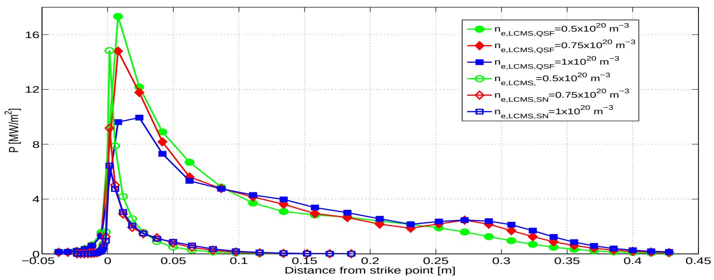


Figure 2: Power density profiles for the three considered standard H-mode density scenarios for SN (open symbols) and QSF (solid symbols) configurations.

density scenario, where a roll-over of the density and a drop of the target electron temperature below $5eV$ is observed; in SN we get these conditions only for $n_{e,LCMS} = 1.4 \times 10^{20} m^{-3}$.

Conclusions abd future work

In this paper a preliminary scoping study on QSF alternative magnetic configuration has been performed with the 2D edge code EDGE2D-EIRENE for the DTT machine and compared with the standard SN H-mode scenario. The results shows that the QSF configuration is able to drastically reduce the thermal loads by broadening the power deposition on larger surface area compared to SN. This behaviour is mainly related to the higher flux expansion on the divertor plates. Therefore, a more detailed analysis should consider also the impurity seeding and the effect of the different magnetic topology on the radiative power. Finally, an analysis of a Liquid Lithium divertor has started. However, due to numerical problems, this work is still on going.

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