Turbulence and flows in the plasma boundary of snowflake magnetic configurations

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The power exhaust through the scrape-off layer (SOL) in fusion reactors is expected to be significantly higher than in ITER, thus questioning the extrapolation of the ITER exhaust solution to these devices. The snowflake (SF) magnetic configuration is one of the alternative exhaust configurations being considered to mitigate the heat vessel loads in fusion reactors. The SF configuration features a second-order null of the poloidal magnetic field, i.e. a point where the poloidal magnetic field and its spatial derivatives vanish. As a consequence, the null-point is connected to the wall through four legs, which define four strike points. The presence of the four strike points allows for a heat flux distribution on a larger area compared to standard divertor configurations that feature two strike points.

SF configurations are obtained experimentally by generating two first-order X-points close to each other. When the two X-points coincide, a second-order null point is obtained. However, in practice, the two X-points never coincide perfectly and, according to their relative position, we distinguish between the snowflake plus (SF+) and snowflake minus (SF-). The configuration with the two X-points coinciding is usually referred to as ideal SF. All these configurations have been experimentally investigated in the TCV, NSTX, EAST, and DIII-D tokamaks and are considered for the DTT tokamak. Numerical simulations of SF configurations, carried out by means of the EMC3-Eirene and the SOLPS codes, are unable to reproduce the heat flux distribution observed experimentally, calling for detailed investigations of the turbulence and flows in the SF plasma boundary.

We present the first global turbulent simulations of the plasma dynamics in SF configurations, including the ideal SF, the SF+ and SF- configurations [1]. These simulations carried out by using the GBS code [2], evolve self-consistently the fluctuating and equilibrium quantities, as they result from the interplay of a heat and particle source in the core, turbulent transport, and parallel losses to the vessel wall.

The simulations allow us to disentangle the mechanisms behind the heat flux distribution among the different strike points. As pointed out by our simulations, the heat flux can be reduced by a factor of two in the SF configurations, with respect to single-null configurations. The activation of the unconnected strike points in the ideal SF and in the SF+ configurations, also observed in the experiments, is due to the presence of a steady $\boldsymbol{E} \times \boldsymbol{B}$ equilibrium flow in the null region that provides a cross-field transport mechanism towards the private flux region. The origin, the properties and the effects of this steady $\boldsymbol{E} \times \boldsymbol{B}$ equilibrium flow are carefully analyzed and described as well as its dependence on the direction of the toroidal magnetic field and on the distance between the two X-points.

References:

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[2] P. Paruta, P. Ricci, F. Riva *et al.*, Physics of Plasmas **25** (2018), 112301