Energetic particle confinement and stability in the Spherical Tokamak for Energy Production

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The UK has launched a programme to build a prototype fusion power plant, the Spherical Tokamak for Energy Production (STEP), generating fusion power ~1 GW and net electrical power ~100 MW. Good confinement and low redistribution of fusion α-particles will be required to ensure acceptable first wall power loads and to realize the target plasma scenario. Waves in the electron cyclotron range will be used for external current drive, and therefore α-particles will be the only significant fast ion species. We will report on modelling of α-particle confinement and of toroidal Alfvén eigenmodes (TAEs) driven by these particles in the target scenario. Results have been obtained so far for two scenarios: STEP Prototype Reactor (SPR)-008 with major radius R_0 = 3.6m, toroidal field on-axis B_0 = 2.3T, plasma current I_p = 23MA and volume-averaged beta β = 0.22; and SPR-014, with R_0 = 4.7m, B_0 = 4T, I_p = 23MA and β = 0.07. Prompt and toroidal field (TF) ripple-induced losses of α-particles and associated power loads on plasma-facing components have been calculated using the LOCUST code for a range of ripple parameters (the number of TF coils N_{coil} and the major radii of their outer limbs R_{coil}). In both SPR-008 and SPR-014 the peak power fluxes due to prompt alpha-particle losses occur in the upper divertor whereas those due to ripple occur in the main chamber, where the maximum tolerable fluxes are relatively low (~0.5MWm^{-2}). For SPR-008 acceptable power loads are achieved with N_{coil} =12 and R_{coil} = 8.0m. For SPR-014 R_{coil} would need to be as high as 11m if 12 coils were used, but a 10m coil radius would be acceptable if N_{coil} = 14. TAE stability calculations for STEP performed using the HAGIS and HALO codes will also be presented. Due to the presence of high magnetic shear in the plasma edge, many TAEs exist in STEP plasmas, some of which have intrinsic growth rates as high as γ/ω ~ 0.2. However bulk ion damping of these modes in flat-top conditions is generally even stronger due to high β (meaning that the Alfvén and ion thermal speeds are not widely-separated) and TAEs are therefore unlikely to be driven unstable during this phase. Net damping of TAEs is found even in the case of SPR-014 despite lower β. Further stability analysis remains to be carried out, in particular of finite temperature effects, TAE excitation during plasma ramp-up, and higher order (ellipticity-induced and noncircular triangularity-induced) Alfvén eigenmodes.

This work was funded by the UK Department for Business, Energy and Industrial Strategy.