Confinement of fusion alpha-particles and Alfvén eigenmode stability in the Spherical Tokamak for Energy Production (STEP)

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The Spherical Tokamak for Energy Production (STEP) programme is focused on designing and building a prototype fusion power plant that will generate approximately 1.5-1.8 GW of deuterium-tritium fusion power. To achieve this, the alpha-particles generated through fusion must be confined sufficiently to maintain thermonuclear bulk ion temperatures in the plasma core and to protect the wall from excessive damage. Microwaves will be used for external heating and current drive, making alpha-particles the only significant fast ion species. We have modelled the confinement of fusion alpha-particles and the stability of toroidal Alfvén eigenmodes (TAEs) driven by these particles in several candidate STEP flat-top operating points to check their viability. We use the LOCUST [1] and ASCOT [2] codes to model the alpha-particle confinement and heat-load distribution on the wall, and the HALO code [2] to model the TAEs. The deconfining effects of toroidal field (TF) ripple, resonant magnetic perturbations imposed to suppress edge localised modes (ELMs), and controlled resistive wall modes (RWMs), have all been modelled. We find that acceptable alpha-particle confinement in terms of wall power loading can be achieved in candidate flat-top operating points, but the results are sensitive to some of the system parameters. For example, a change in the phase difference between the currents in upper and lower ELM suppression coils can increase the maximum power load on the first wall due to alpha-particle losses by as much as a factor of 10. Thus, alpha-particle losses need to be considered when selecting ELM suppression coil configurations. Ripple losses can be made acceptably low by choosing either the number of TF coils or the major radius of the TF coil outer limbs to be high enough. Losses due to field perturbations associated with controlled RWMs have been found to be acceptably low, but the losses may increase when noise in the control system is taken into account. Alpha-particles in STEP provide strong intrinsic drive of TAEs but, in the flat-top cases examined so far, bulk ion Landau damping of these modes has been found to be even stronger. Physically, this result arises from the bulk ion thermal speed being a substantial fraction of the shear Alfvén wave phase speed (i.e. the Alfvén speed) at the large plasma beta values required in the STEP plasma core. However, it is possible that TAEs could be excited during the ramp-up or ramp-down phases of STEP plasma pulses due to resonances with either fusion alpha-particles or fast electrons arising from the use of microwave current drive.

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[3] Fitzgerald, M., et al., Computer Phys. Commun. **252** (2020) 106773.