

Free boundary equilibrium modelling of disruption scenarios for STEP

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Introduction

Reactor scale devices such as STEP will require robust systems for the mitigation and control of disruptions. Two such examples of relevance to spherical devices are vertical displacement events (VDEs) as well as sudden changes in poloidal β and internal inductance (li) through, for example, a loss of confinement. In order to model the two scenarios for the design of control systems and to estimate disruption loads the quasi-static equilibrium model FEEQS has been employed.

Vertical Displacement Events (VDEs)

VDEs can be split into four distinct phases:

- Diverted phase: plasma drifts vertically (~ 0.5 s)
- Limited phase: plasma makes contact with a limiter, depositing thermal energy W_{th} (~ 0.1 s)
- Thermal quench: once $q_{edge} = 2$ the remaining thermal energy is lost rapidly (~ 2.5 ms)
- Current quench: once $W_{th} = 0$ the plasma current is rapidly lost (~ 23 ms)

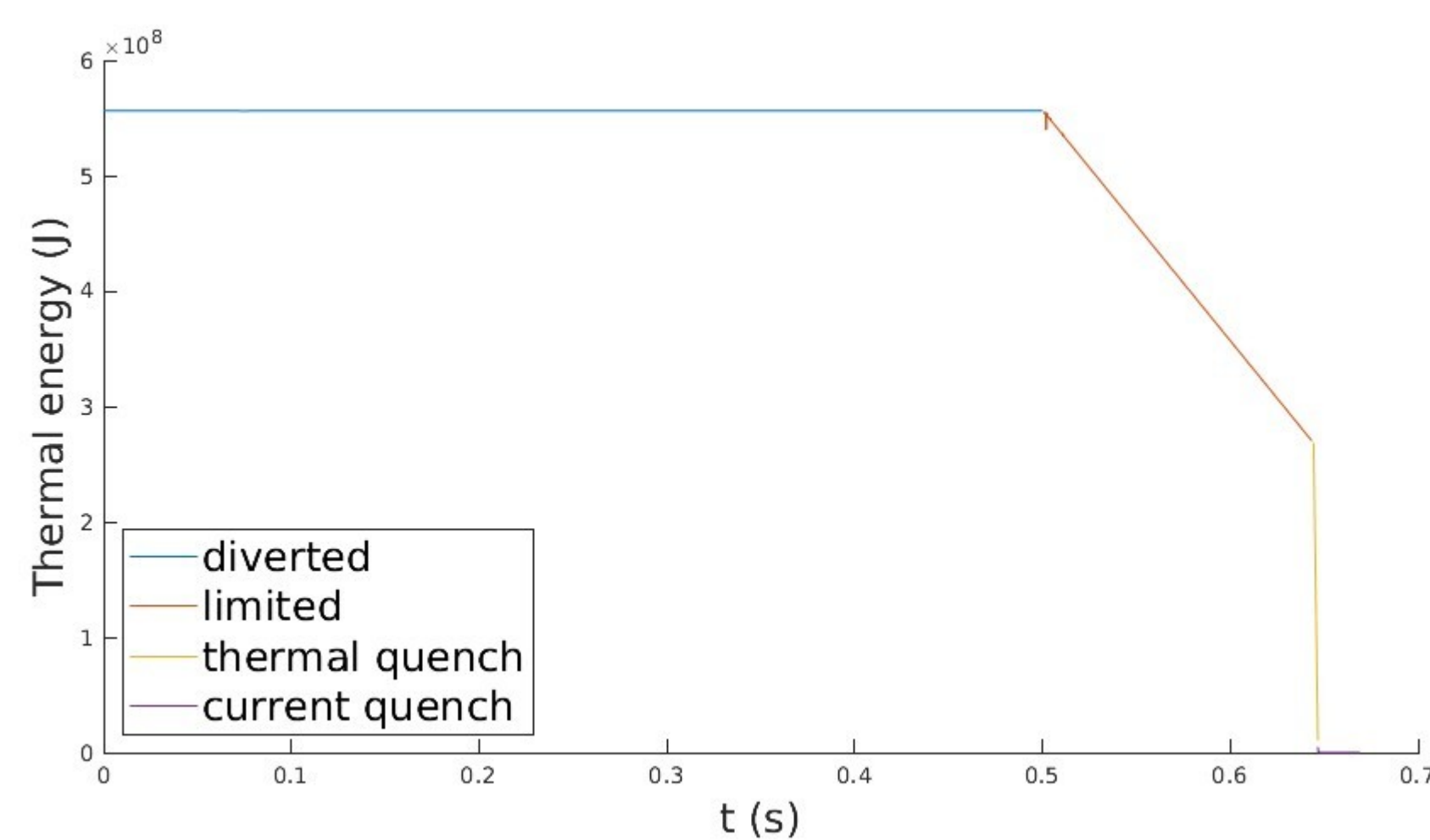


Fig. 1: Target thermal energy as a function of time used in the simulations. The time durations for the thermal and current quench phases are approximates for a hot VDE

This is modeled in FEEQS by modifying the $P'(\Psi)$ and plasma current to achieve targeted values based on estimates for the phase durations.

Limiter shaping

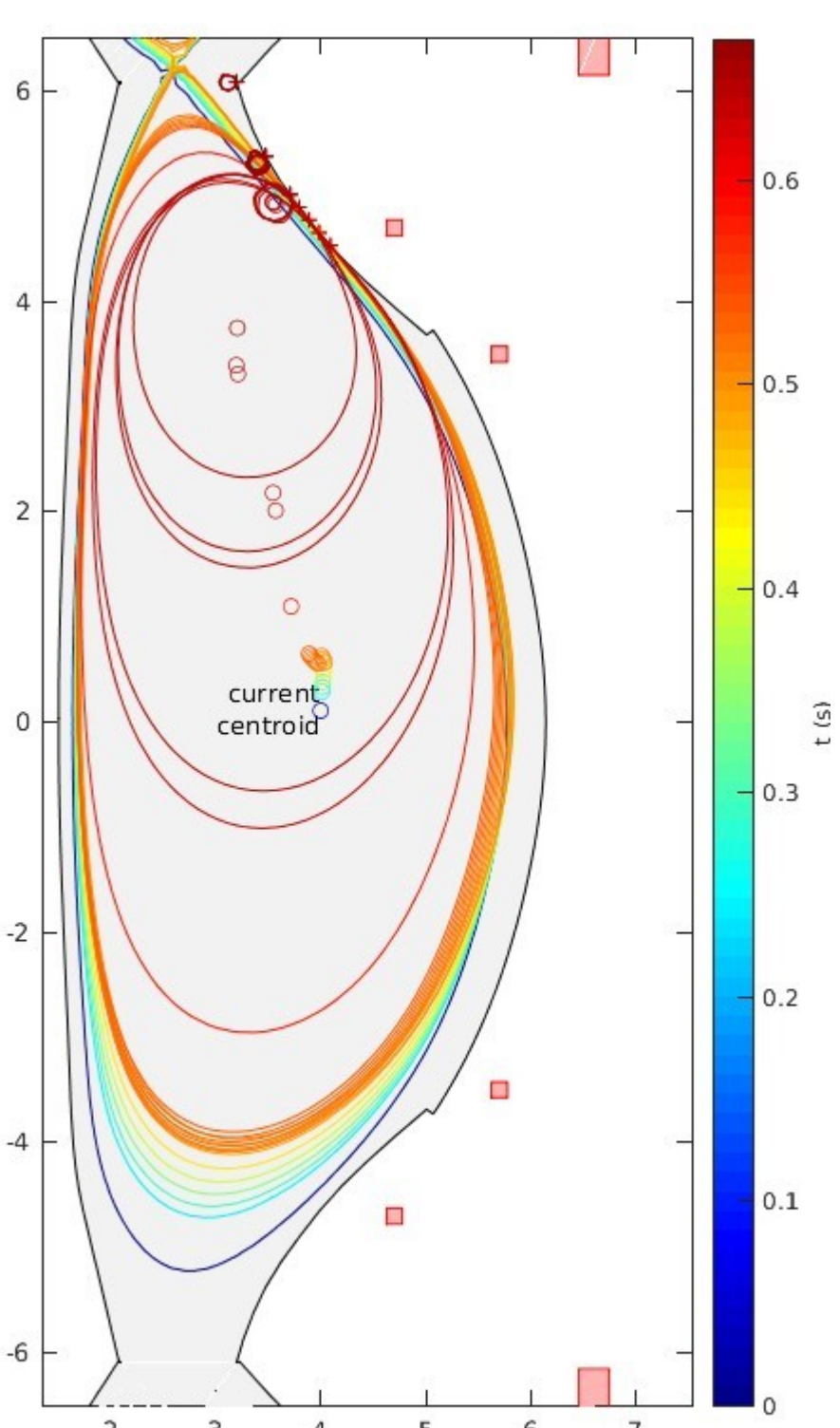


Fig. 2: Last closed flux surface (LCFS) of a STEP plasma undergoing a VDE

The equilibrium as a function of time was successfully computed using FEEQS. From there the poloidal flux and boundary shape can be used in other codes to assess the heat loads to the limiter as well as magnetic loads to the structure.

In order to get the plasma to collide with the limiter some shaping of the first wall was required. For a conformal wall too close to the plasma the impact is below the limiter, too far and the plasma continues up into the divertor. The current solution is to curve the limiter section towards the plasma.

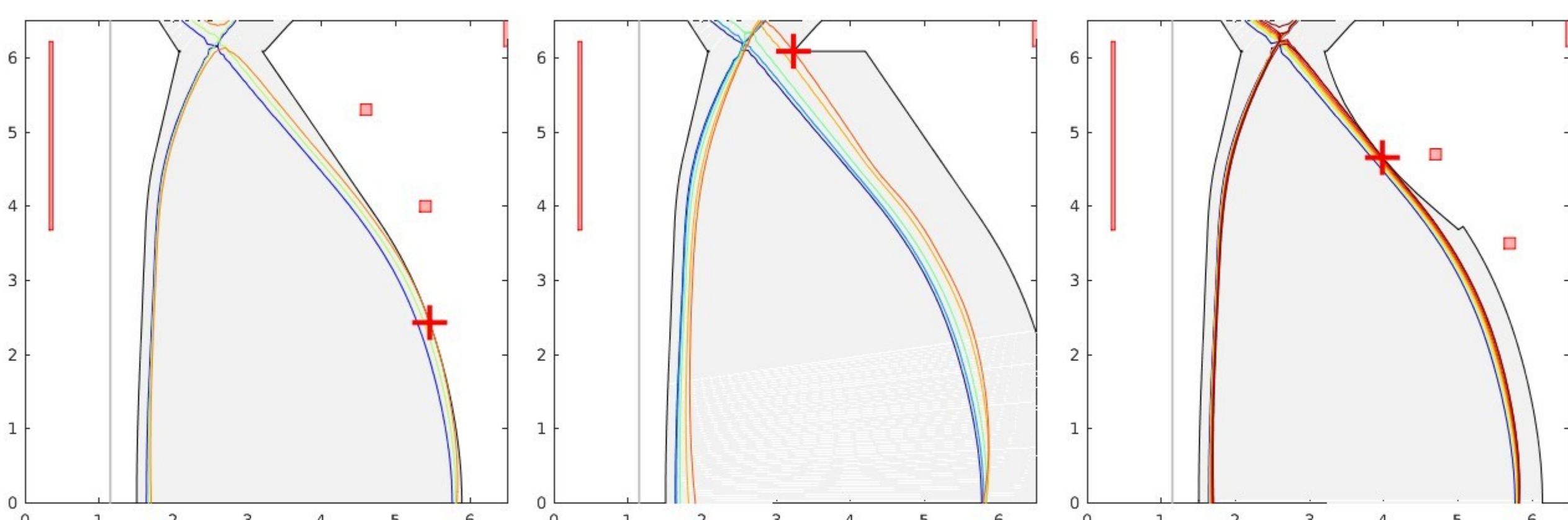


Fig. 3: VDE simulations demonstrating the wall shaping requirements imposed by the tight aspect ratio. In the leftmost case the plasma impacts the wall below the limiter, in the centre it continues up into the divertor. In the rightmost case the addition of an inward curvature to the first wall results in the plasma striking the wall at the intended position.

Radial Drift

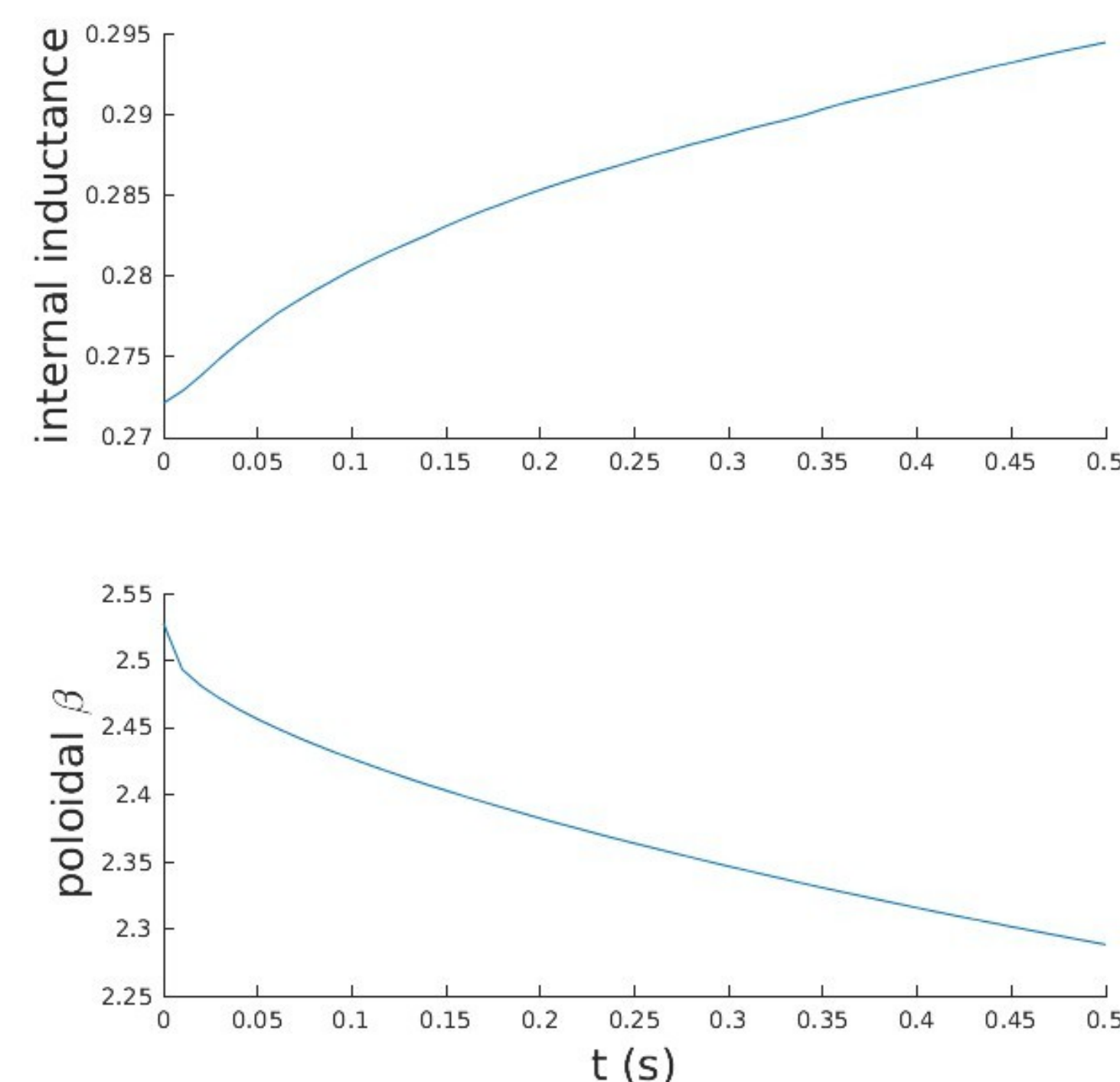


Fig.4: Evolution of the plasma parameters as calculated in JETTO after the edge confinement was removed from a representative steady state scenario.

In order to model such a scenario and assess potential control solutions the fixed boundary equilibrium code JETTO was employed to model the changes in plasma parameters after a sudden removal of the edge confinement. This data was then used in FEEQS to model the evolution of the plasma boundary in the presence of varying coil currents and currents induced in passive structures.

Control methods

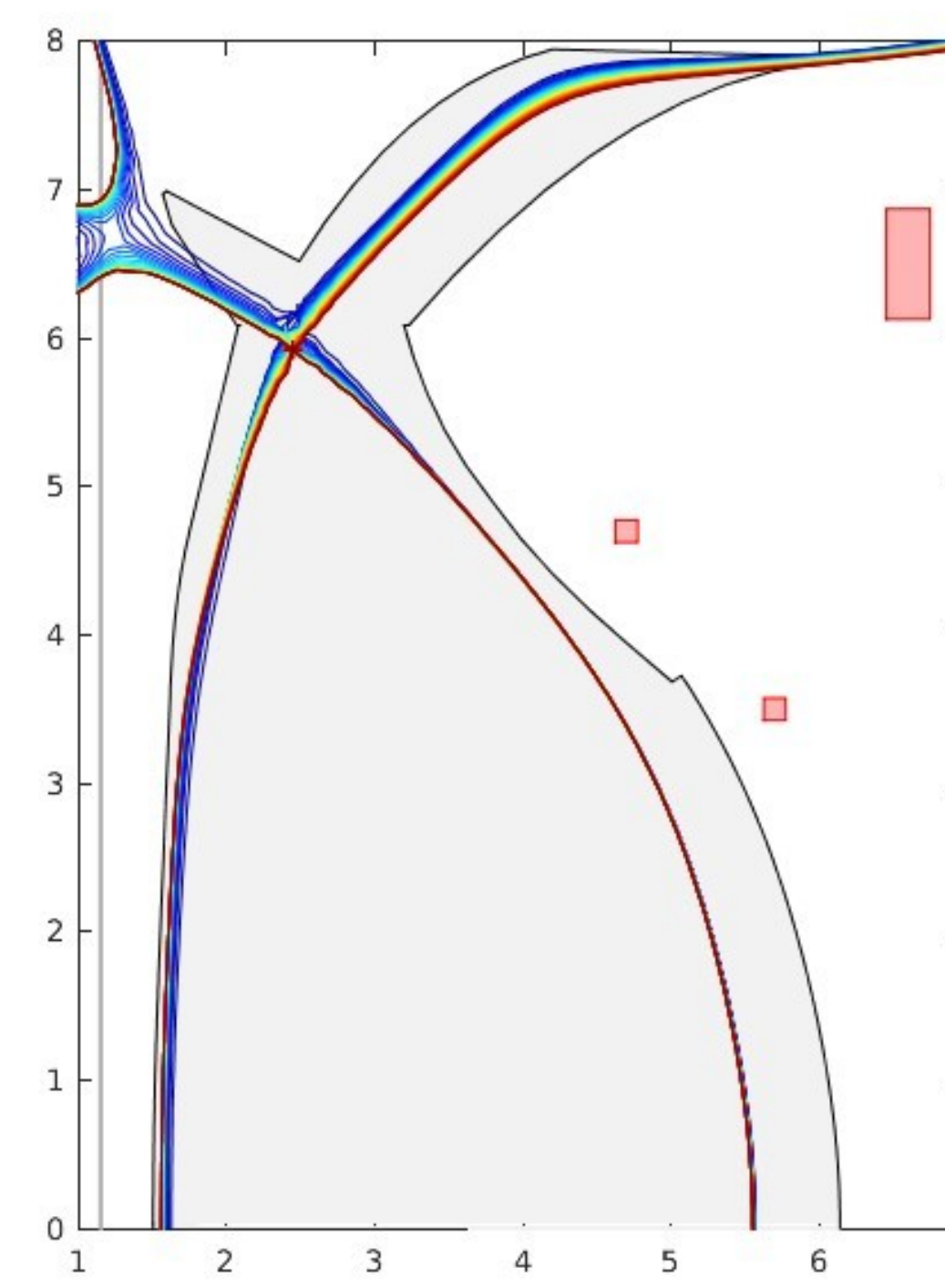


Fig. 5: evolution of the LCFS as the plasma parameters are changed according to Figure 4. Note the pink squares denoting the copper hoops and PF coil.

Figure 6 shows the results of three different simulations. While the pf coil ramp alone is enough to prevent the plasma from striking the wall, the radially coupled hoops improve on this by a few cm.

As demonstrated in figure 5, both active and passive control was considered. For passive control two pairs of toroidally conductive copper hoops were wired to couple with the radial motion of the plasma. For active control one of the poloidal field coils was ramped down at a rate of 1 MA/s. Note that at this stage engineering concerns have not been considered as the work intends to compare control methods against each other.

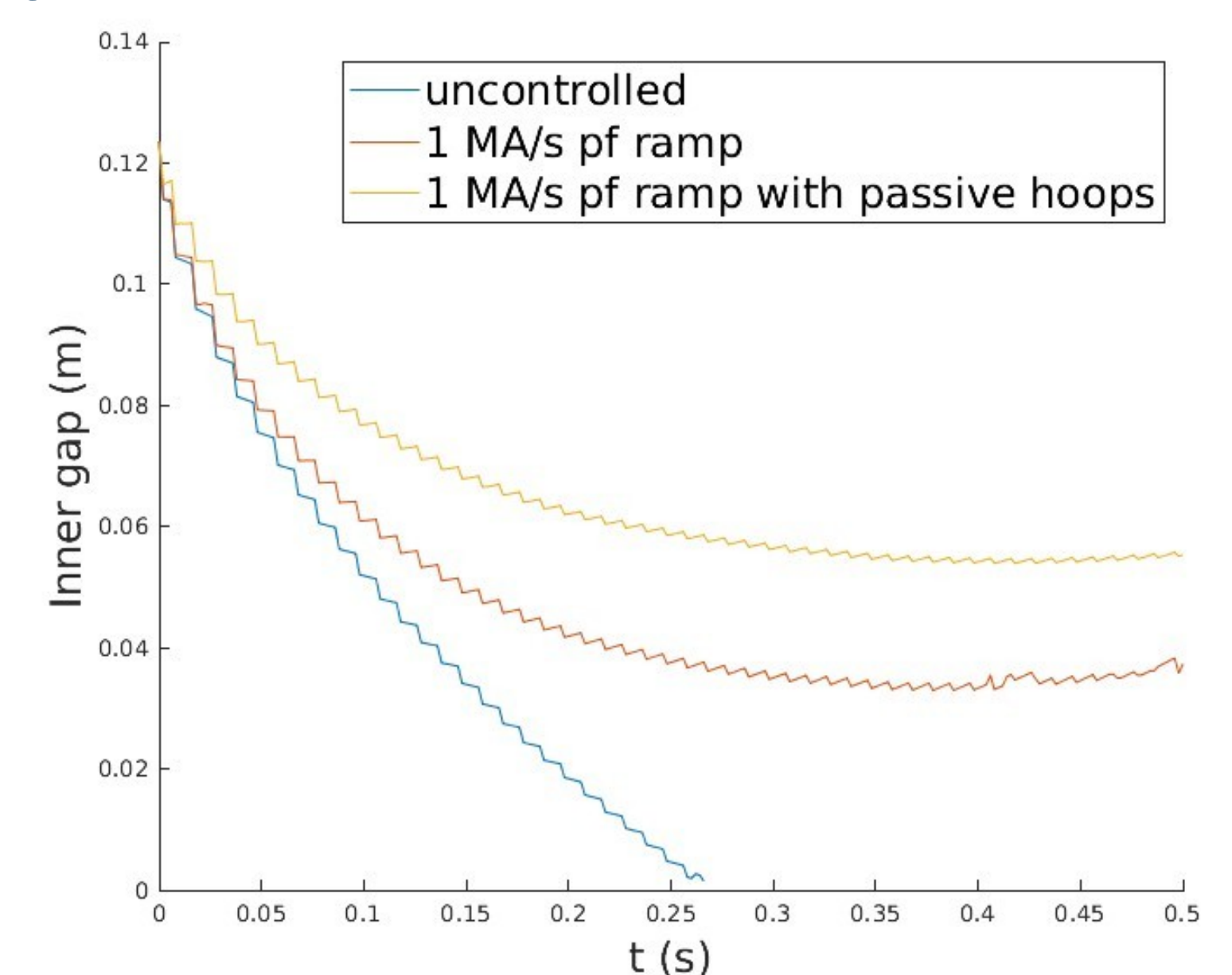


Fig. 6: The inner gap as calculated by FEEQS as a function of time for a range of control scenarios.

Conclusions and future work

- Initial work has been carried out to perform free boundary equilibrium analysis for transient events on STEP.
- The results have been used to inform decisions on wall shaping and to qualitatively assess control scenarios.
- As the VDE simulation is currently based on assumed rates, the analysis should be repeated with an MHD code such as JOEAK for better accuracy
- The JETTO simulations were based on a static plasma in one scenario, this should be diversified to properly understand control requirements.