Optimisation of Resistive Wall Mode Control in STEP

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The Spherical Tokamak for Energy Production (STEP) is a UKAEA program that aims to deliver a prototype fusion energy plant and a path to commercial viability of fusion [1]. The low aspect ratio spherical tokamak is attractive because of its potential to achieve high normalized beta β_N operation, and fusion power ~ β_N^2. To fully exploit this, and to maximise economic attractiveness, operation above the no-wall β-limit is desirable, where the resistive wall mode (RWM) must be controlled either by passive or active control, since otherwise this may lead to major disruption.

Previously, it was found that passive stabilization of the RWM in STEP gives a relatively small increase in β_N above the no-wall limit, relying on toroidal plasma flow and drift kinetic resonance damping (from both thermal and energetic particles) [2]. In order to optimise performance in STEP from an MHD viewpoint, active control of the unstable RWM appears to be a necessity. In this work, the MARS-F code [3] is utilized to model feedback schemes for controlling the n=1 RWM in STEP, assuming a set of active coils located near the outboard mid-plane of the torus. Results show that, with the flux-to-voltage control scheme which is the basic choice, a proportional controller alone does not yield complete stabilization of the mode. Adding a modest derivative action, and assuming an ideal situation without any noise in the closed loop, the RWM in STEP can be fully stabilized in the presence of plasma flow.

With more realistic control assumptions, i.e. the presence of sensor signal noise in this study, the RWM feedback is found to be of a more subtle issue in STEP. This is partially due to the fact that the derivative action tends to amplify the sensor noise, and partially related to the statistic nature of the problem leading to difficulties e.g. in judging the success of mode suppression in certain cases. To model the sensor signal noise, random perturbations with a normal distribution, with zero mean and standard deviation of σ<0.1 G, are injected into the magnetic field measured by pickup coils during initial value closed loop simulations. A criterion, based on the total perturbed magnetic energy of the system, is proposed to judge the control loop success. To obtain reliable results, 100 initial value closed loop simulations are performed for the same feedback configuration, with statistics drawn in terms of the success rate for the RWM suppression. As a key finding, success rates exceeding 90% are achieved, and generally increase with the proportional feedback gain. On the other hand, the required control coil voltage also increases with feedback gain and with the sensor signal noise.

Further studies, to be reported at the conference, will investigate alternative criteria (e.g. that based on the n=1 locked mode amplitude to trigger a disruption [4]) for the closed loop stability in the presence of noise, as well as schemes of sensor noise filtering to improve the control performance.

[1] https://step.ukaea.uk/

[2] http://ocs.ciemat.es/eps2021pap/pdf/P1.1042.pdf

[3] *Liu Y Q et al 2000 Phys. Plasmas* ***7*** *3681*

[4] *de Vries P C et al 2016 Nucl. Fusion* ***56*** *026007*