Modelling-based high $\beta_N$ RMP spectrum optimization for ELM mitigation

D. A. Ryan\textsuperscript{1,2}, Y. Q. Liu\textsuperscript{2}, P. Piovesan\textsuperscript{3}, A. Kirk\textsuperscript{2}, M. Dunne\textsuperscript{4}, W. Suttrop\textsuperscript{4}, B. Dudson\textsuperscript{1},

ASDEX-Upgrade team\textsuperscript{4} and EUROfusion MST1 team\textsuperscript{6}

\textsuperscript{1} Department of Physics, York Plasma Institute, University of York, Heslington, York, UK
\textsuperscript{2} CCFE, Culham Science Centre, Abingdon, Oxfordshire, UK
\textsuperscript{3} Consorzio RFX, Corso Stati Uniti 4, 35127 Padova, Italy
\textsuperscript{4} Max Planck Institute for Plasma Physics, 85748 Garching bei München, Germany
\textsuperscript{6} see http://www.euro-fusionscipub.org/mst1

Edge Localised Modes (ELMs) are a repetitive MHD instability prevalent in modern tokamaks, which may be mitigated or suppressed by the application of resonant magnetic perturbations (RMPs) [1]. The applied spectrum of the RMPs can be tuned for optimal ELM control, by introducing a toroidal phase difference $\Delta \Phi_{ul}$ between upper and lower rows of RMP coils. This flexibility may be critical for ITER in view of the requirement of robust ELM control across a wide range of plasma parameters, notably the normalised pressure $\beta_N$ and the safety factor $q$. This motivates a study of the dependence of the optimal coil phase difference $\Delta \Phi_{ul}$, on plasma parameters $\beta_N$ and $q_{95}$. Using calculations of the plasma response to the applied RMPs, criteria may be devised for the optimization of the RMP spectrum, which have had some success in interpreting ELM mitigation experiments in MAST [2,3] and ASDEX Upgrade [4]. In this work, a set of tokamak equilibria spanning a large range of ($\beta_N$, $q_{95}$) is produced, based on a reference equilibrium from an ASDEX Upgrade RMP experiment. The MARS-F/K code [5,6] is then used to compute the optimal $\Delta \Phi_{ul}$ across this equilibrium set, using stochasticity-based and plasma displacement-based optimisation criteria. It is found that for a given plasma boundary shape, the optimal $\Delta \Phi_{ul}$ is determined mainly by $\beta_N$, $q_{95}$, and toroidal mode number $n$ of the applied RMP. For fixed $\beta_N$, the optimal $\Delta \Phi_{ul}$ increases with $q_{95}$, whereas for fixed $q_{95}$, the optimal $\Delta \Phi_{ul}$ decreases with $\beta_N$. It is also found that the shift in $\Delta \Phi_{ul}$ caused by the inclusion of the plasma response, is robustly between 60° - 90°, which may allow the optimal $\Delta \Phi_{ul}$ to be approximately predicted without requiring a plasma response computation.